State of California
The Resources Agency
DEPARTMENT OF WATER RESOURCES
Northern District

EAGLE LAKE

Alternative Plans for Controlling Lake Levels

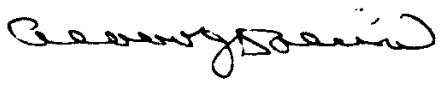
NOVEMBER 1972

FOREWORD

Eagle Lake is now full, blue, and beautiful and everyone wants it to stay that way.

Historically, the water surface of the lake has fluctuated considerably and, since 1950, has been rising. The current high lake level has made Eagle Lake one of the most beautiful natural bodies of water in California with clean, sandy beaches, tree-covered slopes, diverse and important species of fish and wildlife, and clear water. However, roads and lakeshore developments are threatened by the rising water, and uncontrolled leakage through the old Eagle Lake Tunnel has increased.

The Department of Water Resources, in cooperation with the State Division of Highways, undertook a study to evaluate the problems and investigate the possibility of improving the lake environment by various operational plans. Four alternative plans for the control of the water surface elevation of the lake were considered. These alternatives are presented in detail in this report.



Albert J. Dolcini
District Engineer
Northern District

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State of California
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DEPARTMENT OF WATER RESOURCES

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CHAPTER I. INTRODUCTION

Eagle lake is located in northeastern California about 16 miles north of Susanville in Lassen County. The big, blue, 13-mile-long lake is the second largest natural freshwater lake in California, with a surface area that fluctuates from 16,000 to 29,000 acres and a shoreline that exceeds 100 miles in length. Plate 1 shows the lake and the development along its shore.

Eagle Lake is well known for its fish and wildlife. Around its shores are located one of the last known colonies of nesting ospreys and the largest nesting colonies of western and eared grebes in the Western United States. It is the home of the Eagle Lake trout which are native only to Eagle Lake.

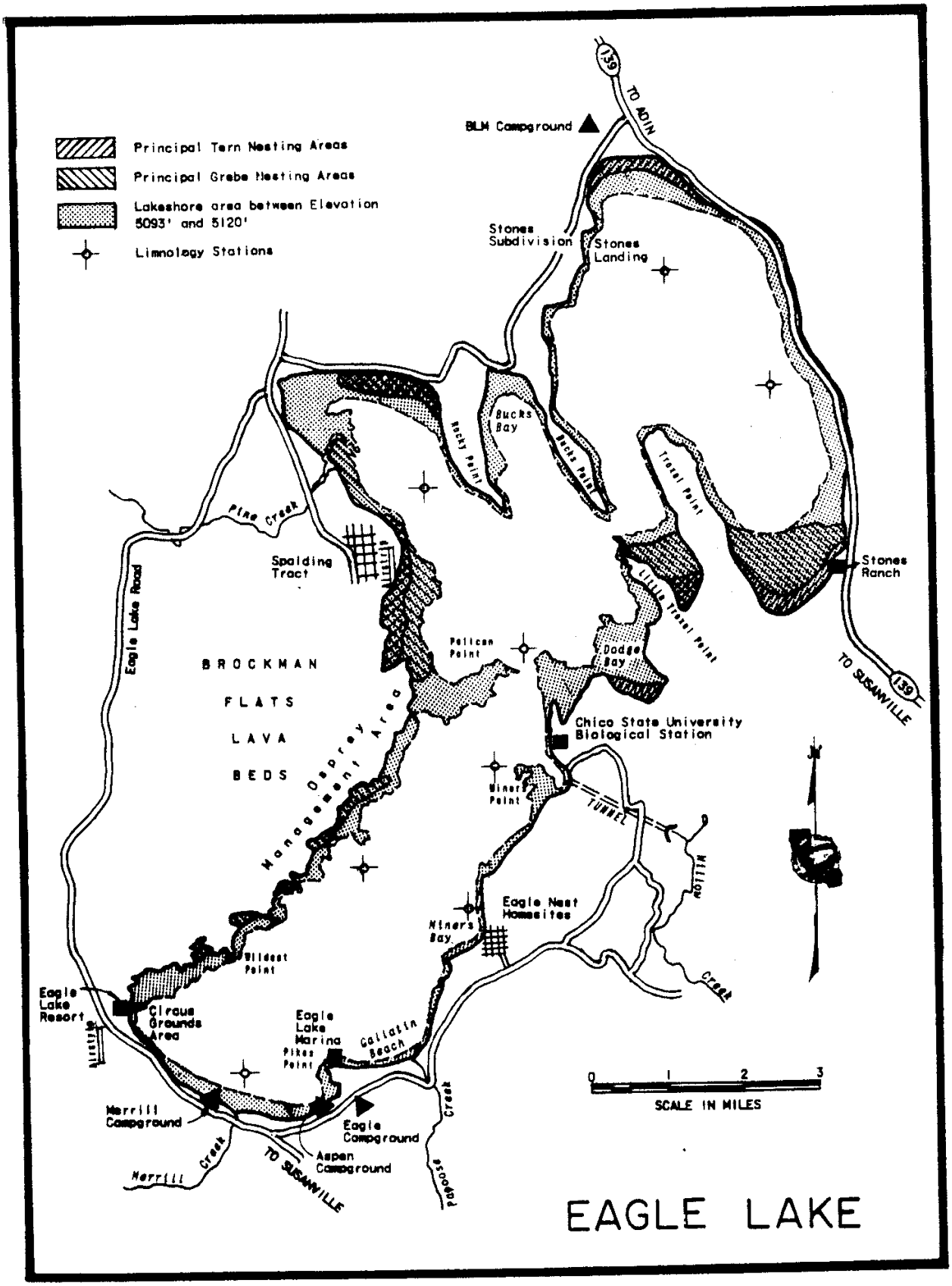
The lake and its immediate drainage are located in a high semi-arid plateau characterized by basaltic lava flows, volcanoes, and cinder cones. Some of the lava flows are fairly recent, having occurred not more than a few centuries ago. The higher western portion of the drainage basin consists mainly of volcanic mountains that form the east flank of the Cascade Range.

Having no natural surface outlet, Eagle Lake is an enclosed basin lake, its elevation fluctuating with variations of inflow. This natural regime was interrupted in 1923 when a tunnel was constructed as part of an irrigation project to divert water from the lake. Diversions from the lake, plus a significant drought from 1922 to 1935, had a profound effect on the lake's elevation, causing it to drop about 27 feet. Since reaching its lowest recorded elevation of 5,092 feet in 1950, it has risen 15 feet to an elevation of about 5,107.

Although the increased elevation has restored the beauty of the lake, some concerns have been generated by the rising water levels. As the lake surface has risen, uncontrolled leakage through the old Eagle Lake Tunnel has increased, thus allowing more water to leave the basin. Also, roads and lakeshore developments which were constructed while the lake level was low are now being threatened with inundation. The water quality of the lake also presents a potential problem as the eutrophication process appears to be accelerating, possibly from man's activities.

This report presents the results of a study undertaken to evaluate the problems and investigate the possibility of improving the lake environment by considering various possibilities for controlling the water surface elevation. The State Division of Highways, concerned about the possible future inundation of State Route 139, has financially cooperated with the Department of Water Resources in the investigation in hopes that a suitable means of protecting the highway could be found without endangering the fragile environment of the lake.

PLATE I


Principal Tern Nesting Areas
Principal Grebe Nesting Areas
Lakeshore area between Elevation 5093' and 5120'
Limnology Stations
139
TO ADIN
BLM Campground
Stones Subdivision
Stones Landing
Bucks Bay
Rocky Point
Becks Point
Travel Point
Little Travel Point
Stones Ranch
TO SUSANVILLE
Pine Creek
Spalding Tract
Eagle Lake Road
Pelican Point
Dodge Bay
BROCKMAN FLATS LAVA BEDS
Osprey Area
Management
Chico State University Biological Station
Miner Point
TUNNEL
ROTTEN
Eagle Nest Homesites
Miners Bay
Wildest Point
Eagle Lake Resort
Circus Grounds Area
Eagle Lake Marina
Pikes Point
Gallatin Beach
Merrill Campground
Eagle Campground
Aspen Campground
Merrill Creek
Creek
Indian Creek
Pelican Creek
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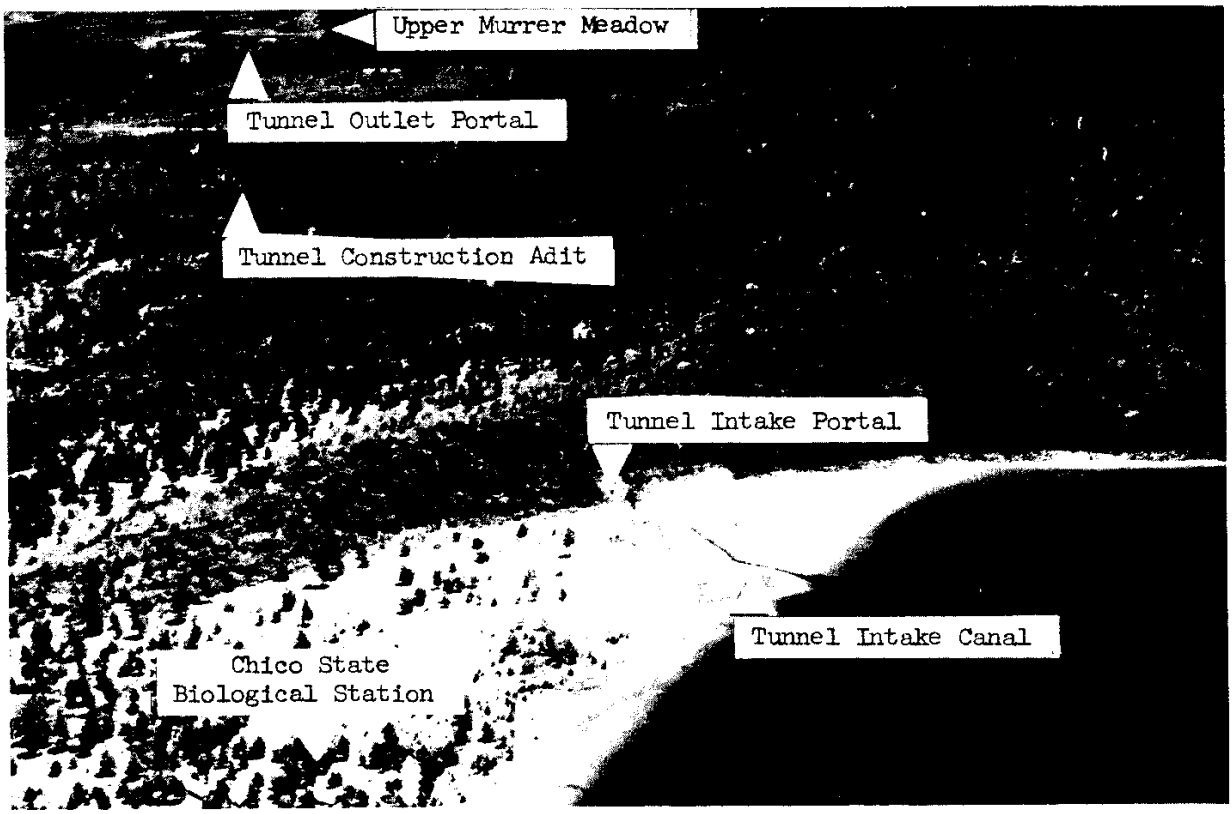
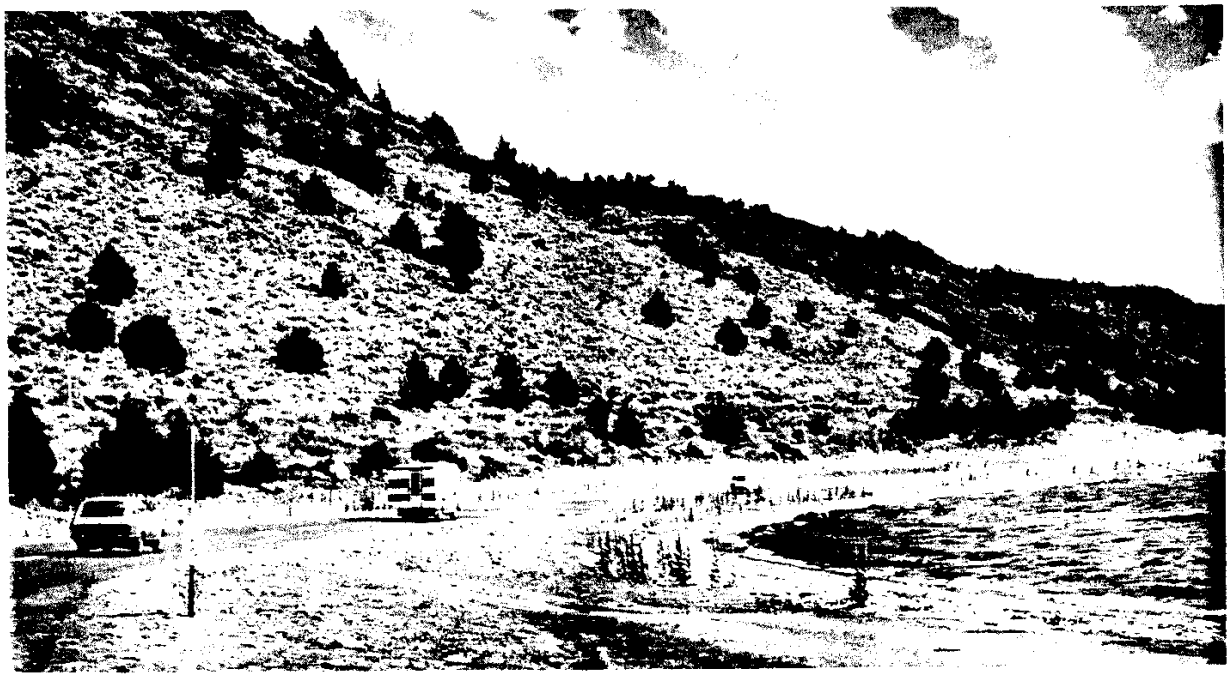
SCALE IN MILES
EAGLE LAKE



Looking Southeast Over Eagle Lake Toward Eagle Lake Tunnel



State Route 139 Along Northeast Shore of Eagle Lake. Highway section in foreground was abandoned in 1970 due to inundation and wave damage.

Scope

Due to funding limitations, this study was conducted at a low reconnaissance level. Various alternatives available for management of the lake were considered and the following four alternatives were evaluated: (1) seal the tunnel and let the lake return to its natural condition, (2) leave everything as it is today, (3) release water during periods of high lake levels to control maximum lake level to elevation 5,106 feet, and (4) release water to control maximum lake level to elevation 5,115 feet.

Maintaining and improving the environment of the lake, especially for the famous Eagle Lake trout and the extensive bird populations, was a primary objective of this study. No consideration was given to the development of a firm irrigation water supply from the lake. However, under alternatives whereby water would be released from the lake, it could be assumed that some of the water would be released under a schedule which would allow its beneficial use in the Willow Creek and lower Honey Lake Valleys.

Physical features necessary for accomplishment of the various alternatives were delineated. Cost estimates were made for each feature, and all foreseeable impacts from the various alternatives were evaluated.

Of primary concern is the long-range effect on fish, wildlife, recreational development, and water quality. The Department of Fish and Game evaluated the fish and wildlife aspects, the Department of Parks and Recreation evaluated the recreation aspects, and the Department of Water Resources evaluated the water quality, legal, engineering, and economic aspects.

History

In geologic terms, Eagle Lake is relatively recent. It was formed when volcanic activity blocked Willow Creek, a tributary to the Susan River and Honey Lake.

Since the first settlement in the area by the white man, Eagle Lake has been considered a potential source of water supply for the arid Honey Lake Valley. The earliest attempt to tap the lake was in 1875. At that time the Lassen Flume and Land Company attempted to drill a tunnel from near Upper Murrer Meadow to the lake. This plan, which is now referred to as the Merrill Project, failed from lack of finances. In 1891, a plan was developed by the Eagle Lake Land and Irrigation Company to pump water into Willow Creek. Water was actually pumped from the lake for a few months, but this project, like its predecessor, failed.

The last attempt to develop a water supply from the lake was made by Leon Bly. His plan, which involved construction of a tunnel from the lake to Willow Creek, is known as the Bly Project. Mr. Bly was instrumental in forming the Tule Irrigation District and reorganizing the Baxter Creek Irrigation District. These districts purchased the constructed project facilities from Mr. Bly.

In 1921 work commenced on a 7,300-foot tunnel from Upper Murrer Meadow toward the lake. Water was to enter Willow Creek to be rediverted

Intake Portal of Eagle Lake Tunnel

Outlet Portal of Eagle Lake Tunnel

through a series of canals, flumes, and siphons to the areas of use in Honey Lake Valley. The plan called for the tunnel to tap the lake 45 feet below the surface at that time. However, as the tunnel construction approached the lake, leakage from fractures in the lava created such a problem that the tunnel had to be inclined upwards to the lake surface. The tunnel was completed in 1923. A profile of the tunnel as it exists today is shown on Plate 2 at the back of the report.

Water was diverted intermittently through the tunnel from 1923 to 1935 when the tunnel entrance was blocked. It is estimated that the total diversion from the lake was about 310,000 acre-feet. During that period the lake elevation declined approximately 27 feet, from elevation 5,119 to elevation 5,092. Much of this decline, however, is attributed to the low runoff during the drought that occurred between 1924 and 1938.

Since 1935, the Tule and Baxter Creek Districts have gone through bankruptcy proceedings. The Baxter Creek Irrigation District has been dissolved; the Tule Irrigation District remains in existence but is inactive. All assets of the districts have been purchased by the Honey Lake Land Company whose sole owners are James K. and William R. Buell.

Previous Studies

Subsequent to tunnel construction several investigations have been conducted to estimate the water supply of Eagle Lake. The apparent earliest published report was prepared by J. P. Lippencott, a consulting engineer from Los Angeles. That study was done in 1926 for the Tule and Baxter Creek Irrigation Districts and was undertaken to estimate the yield available through the district's tunnel. The report concluded that an average of 35,000 acre-feet per year would be available, assuming a greatly reduced surface area of the lake.

In 1957, the Department of Water Resources prepared an office report on Eagle Lake in response to a request by Assemblywoman Pauline Davis. That report summarized the conditions at the lake and presented a potential water development project in conjunction with a reservoir on Willow Creek. The proposed project included a dike across the lake at Pelican Point with diversion facilities to route Pine Creek from its natural outlet to the south portion of the lake. Under the plan, the northern part of the lake, deprived of its water supply, would therefore become dry. The estimated safe yield of the proposed project was 20,000 acre-feet per year.

In 1961, the Department of Water Resources prepared water supply information for the Department of Fish and Game for submission at water rights hearings held relative to applications to divert water from the lake through Willow Creek. The report estimated the average annual inflow to the lake and evaluated the potential of a firm yield water supply from the lake. Studies conducted at that time estimated the inflow to the lake to be 47,700 acre-feet per year. An operation study of the lake showed that about 5,000 acre-feet of annual yield could be developed without severely reducing lake storage or area.

In 1965, Professor S. T. Harding published a report entitled "Recent Variations in the Water Supply of the Great Western Basin" that included a chapter on Eagle Lake. Professor Harding made an extensive study of the lake and estimated that the average annual water supply for the period 1875 to 1960 was 52,000 acre-feet. He also estimated the water surface elevations dating back to the year 1400 and concluded that the lake's maximum historic elevation was 5,125 feet, which occurred in 1916.

Numerous studies have been made of the biological characteristics of the lake and its basin. Many of these have been done by students and faculty members of Chico State University, which maintains a biological station on the lake. The Department of Fish and Game has gathered and evaluated considerable data on the fishery. Many of these data are included in Fish and Game's "Report on Proposed Water Appropriations Affecting the Fish and Game Resources of Eagle Lake, Lassen County", August 1961.

A planning study of Lassen County was undertaken in 1968 by the firm of Williams, Cook, and Mocine. The Eagle Lake Plan, an elemant of the county general plan, described in general terms a desirable growth pattern for public and private facilities in the area surrounding Eagle Lake. The plan generally prescribes that the use of the lake and its environs is for recreational purposes of an intensity and character in keeping with the wilderness setting and the inherent beauty of the area.

Current Studies by Other Agencies

The State Water Resources Control Board currently has Kaiser Engineers under contract to prepare a water quality control plan for the Lahontan area, which includes Eagle Lake. The plan will cover the effect of development and land use on the water quality of the area.

Chico State University is currently attempting to develop a nutrient budget for the lake. This budget will show nutrient income, outgo, amount in the system, and rate of exchange. As part of this study, complete hydrology of the basin will be evaluated. Results of this work will hopefully be available by 1974 and should play an important role in future planning efforts at the lake.

The Bureau of Land Management has recently prepared a land use plan for its Willow Creek unit which includes Eagle Lake. The plan is called a "management framework plan" and covers use of all Bureau of Land Management lands in the unit.

The U. S. Forest Service is involved in continous planning efforts for use of its lands around the lake. Current study is being directed towards alternative solutions to sewage disposal for its facilities. Recently completed was an osprey habitat management plan for the Lassen National Forest with specific action plans for Eagle Lake.

Planning efforts in the Eagle Lake Basin are currently being formulated and coordinated by an interagency planning board. The board has representatives from the Lassen County Board of Supervisors, U. S. Forest Service, and Bureau of Land Management.

CHAPTER II. FISH AND WILDLIFE RESOURCES

This section describes the fish and wildlife resources in the Eagle Lake area, which has a tremendous diversity and abundance of fish and wildlife due to the unique variety and quantity of habitat available. Although only six species of fish are present, some of them exist in large numbers. Observed in the area have been at least 65 species of mammals and over 135 species of birds, many of which can be seen by any visitor.

Fish

Of the six species of fish in Eagle Lake, the Eagle Lake trout is the most important economically and socially. Because of its rarity, beauty, and eating quality it is well known and sought after by man. The tui chub, however, is probably more important to the basin's ecosystem since it provides forage for trout and fish-eating birds. This is a unique situation since in most lakes and streams tui chub are considered a "trash fish" and efforts are made for their removal. Fishes of lesser importance in Eagle Lake are the Tahoe sucker, Lahontan redside, Lahontan speckled dace, and brown bullhead.

Twelve exotic species of fish have either been introduced or had access to the lake in the past. Of these only one, the brown bullhead, remains today. The other known species introduced are Great Lakes whitefish, lake trout (Mackinaw), largemouth bass, bluegill, crappie, brown trout, rainbow trout, silver salmon, kokanee, Lahontan cutthroat, and catfish.

Eagle Lake Trout

These unique fish can be distinguished from other trout by their robust body, deep tail, large strong fins, conspicuous adipose fin and large scales. Considerable controversy exists covering the ancestry of the Eagle Lake trout. Some people believe that it is derived from rainbow trout of the western slopes of the Sierra Nevada. Others think it originated from the Lahontan cutthroat trout, a native of the Lahontan drainage which has markings similar to those of the Eagle Lake trout. A few regard it as a hybrid between the cutthroat trout and the rainbow trout. Suffice it to say that they are a spectacular fish found only in Eagle Lake.

Eagle Lake trout live in the lake as adults and have traditionally depended upon Pine Creek and other small tributaries to the lake for spawning. The number of trout in the lake began to decline in the 1930s. Between 1949 and 1960 counts of spawners ranged from 6 to 77 annually. Factors contributing to this decline were low lake levels, low flows in Pine Creek, and an overabundance of eastern brook trout in Pine Creek. Because of the near extinction, a management plan was initiated to insure

the continuation of the species. Today, the Eagle Lake trout fishery is one of the most intensely, and most successfully, managed fisheries in California. This management began in 1950 with 2,000 eggs taken from one adult in Pine Creek and hatched in Crystal Lake Hatchery. Each year since that time adult fish have been captured and spawned at a facility on Pine Creek. The eggs are taken to Crystal Lake and Darrah Springs Hatcheries for hatching and rearing. In addition, adult brood fish are maintained at these hatcheries.

Under natural conditions young Eagle Lake trout spent their first year in the creek where they were spawned. There they grew large enough to compete with other species of fish in the lake. Under present hatchery raising conditions, fish are released in the lake in the spring at an age of about 1 year. These fish are much larger than those which enter the lake from natural spawning in the streams. In addition to fish released to the lake, some are released into upper Pine Creek in the summer shortly after hatching. These fish enter the lake the following spring when Pine Creek commences to flow. When the yearling trout enter the lake, their preferred foods are insects and other invertebrates. In the late spring and early summer, as the new crop of tui chubs becomes abundant, the young trout switch to a fish diet.

The number of trout caught in Eagle Lake each year is small when compared to some other California lakes and reservoirs. The average fish taken, however, is usually large; 3- to 5-pound trout are common.

In recent years the number of people visiting Eagle Lake has increased tremendously. There is little question that fishing for Eagle Lake trout is largely responsible for most of this increase. It is estimated that in 1970 there were 31,400 angler days at the lake. The catch for this effort was about 20,000 fish at a rate of 0.19 fish per hour. In 1969 about 14,000 fish were caught. When the trout population was low, the lake had so few visitors (except during the deer hunting season) that it attracted only people who were seeking isolation and solitude.

Tui Chub

The tui chub is the most common minnow in Great Basin waters. Throughout most of their range these fish tend to be less than 10 inches long, but the variety of chub found in Eagle Lake grows to at least 16 inches long.

Adult chubs have established a distinct migration pattern in Eagle Lake. In the spring they move from deep water at the south end of the lake to the shallows where they spawn on submerged aquatic plants. After spawning, the adults return to deep water again. There may also be a winter migration toward shore since adult chubs have been seen in the Pine Creek estuary in December. The adhesive eggs are distributed throughout the lake on floating fragments of plants that are broken off by the wind and feeding waterfowl. In this manner each crop of young fish is distributed throughout the lake. The eggs hatch in a few days, after which the young fish are found along the shoreline in enormous numbers. This combination of abundance and wide distribution makes the tui chub an excellent forage for the Eagle Lake trout and birds.

Tahoe Sucker

In Eagle Lake, the Tahoe sucker is an unobtrusive fish that makes a grand appearance once each year. When Pine Creek begins to flow in the spring, large schools of these fish migrate from the lake to spawn. The mature males have a bright red strip on their sides and casual observers commonly mistake them for rainbow trout. Tahoe suckers are not as abundant as tui chubs in Eagle Lake; however, they undoubtedly have some value as forage for fish and wildlife.

Lahontan Redside

The Lahontan redside is another species of fish that is seen only when it schools on the annual spring spawning migration up Pine Creek. In Eagle Lake, redsides are not numerous enough to be considered an important forage. Although they seldom grow beyond "bite size", they may provide important forage for other species when small tui chubs are unavailable.

Lahontan Speckled Dace

These small, slender minnows are the least numerous of the Eagle Lake fish. Speckled dace are secretive, unprolific, and nonschooling. As such, they cannot be considered an important forage in Eagle Lake. The adults occupy rocky or gravelly areas around the lake. Spawning takes place in Pine Creek at about the same time the other stream spawning fishes are in the creek.

Brown Bullhead

Brown bullheads are the only introduced species still living in Eagle Lake. They were abundant before the lake receded in the 1930s and have essentially disappeared until recently. Bullheads may have been illegally reintroduced, but it is possible that some of the original fish survived in the vicinity of underwater springs in the lake. Their presence in Eagle Lake will have little effect on the native fishes unless they become numerous enough to consume important quantities of tui chub eggs and young.

Mammals

Muskrats are the only truly aquatic mammals found at Eagle Lake. Racoons, however, forage for fish in Pine Creek and its estuary. Several mammaliam species are dependent upon the shoreline meadows for food. Included are deer, antelope, yellow-bellied marmots, California ground squirrels, Belding ground squirrels, Great Basin pocket mice, and vagrant shrews. Striped skunks depend on an ample supply of bird's eggs in the spring, whereas bats are totally dependent upon the insects that are produced in the lake.

Birds

In this report birds have been categorized into three general groups to express their degree of dependence upon the lake. These are (1) fish-eating birds, (2) birds preferring aquatic plants and crustaceans, and (3) other birds.

Fish-Eating Birds

The tremendous abundance of small fish in the lake provides a unique ecosystem for resident and migrant species of fish-eating birds. Some species of these birds nest at the lake, while others nest elsewhere but feed daily at the lake. The remainder depend on the lake as a resting and feeding station on their annual migrations. Each bird that nests near the lake demands a particular type of nesting habitat.

Ospreys, the "fish eagles", are common nesters around the lake. The osprey's optimum nest site usually contains three features: (1) a large tree with a broken top and side limb support -- adjacent to the nest trees are pilot trees for resting, (2) height sufficient for security and good visibility, and (3) a readily available food supply. Ospreys are unique among birds of prey in that they will nest within sight of their own species. Thirteen of the 24 pairs of osprey known to nest at Eagle Lake are found in a loose colony situated along the west shore. This is one of the last known colonial osprey breeding grounds in the United States. These birds are almost entirely dependent upon fish for food. Ospreys are not deep divers; they catch only fish that swim at or near the surface, or in shallow water.

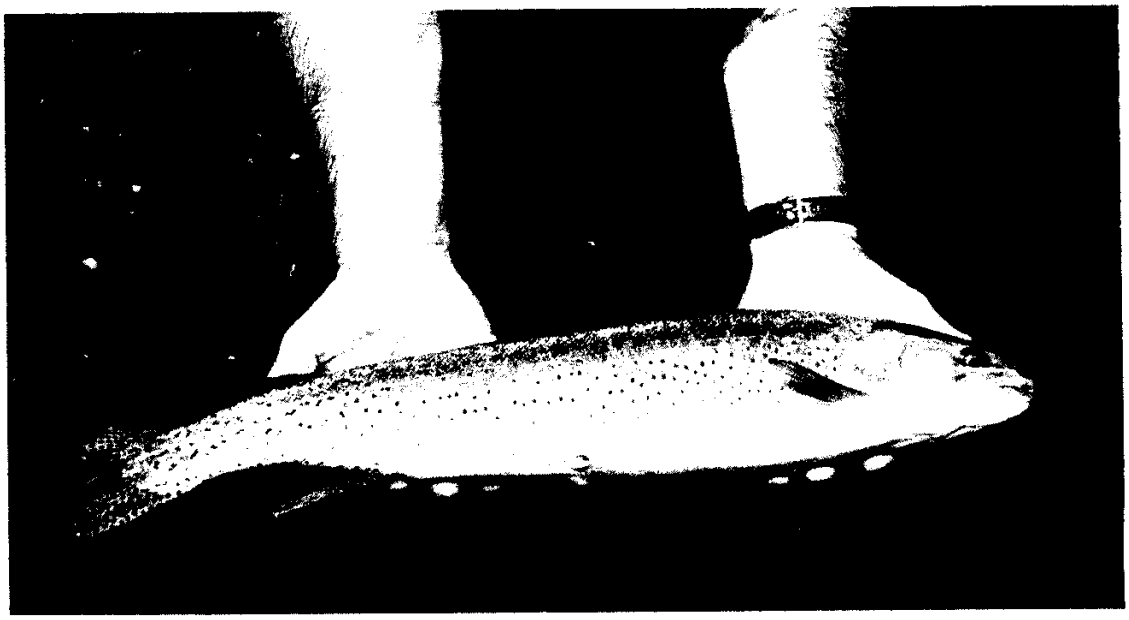
Three pairs of the southern bald eagle, an endangered species, are known to nest around the lake.

Nesting colonies of western and eared grebes at Eagle Lake are probably the largest in the Western United States. In 1971, there were 1,900 breeding pairs of western grebes in eight major nesting colonies near the Spalding Tract and in the bay near the Stone Ranch. Four large nesting colonies of eared grebes, containing 1,800 pairs, were also located near the Spalding Tract.

In 1971, pied-billed grebes used 265 nest sites in four general areas: Stone Ranch, the mouth of Pine Creek, Spalding Tract, and in coves along the western shoreline south of Pelican Point. Unlike the western and eared grebes, the pied-billed grebe is not a colonial nester but all three species nest in *Juncus* and *Scirpus* reed beds.

Two species of terns commonly nest at Eagle Lake in the flooded reed beds around the lake shore. One hundred and fifty pairs of Forster's terns and 300 pairs of black terns nested at Eagle Lake in 1971.

Common mergansers nest in the Pine Creek estuary. Double-crested cormorants have nested on the islands off Pelican Point. There is a great blue heron rookery in a grove of trees near the Spalding air strip. Virginia rails and American coots commonly nest on the reedy



Eagle Lake Trout

Grebe Nest on Eagle Lake

shoreline. Belted kingfishers use cavities in earth or gravel banks for nesting, and this habitat is plentiful in the Pine Creek area.

Fish-eating birds that forage at Eagle Lake but nest elsewhere include the common loon, white pelican, snowy egret, black-crowned night heron, California gull, ring-billed gull, Bonaparte's gull, goldeneye, and the bufflehead.

Birds Preferring Aquatic Plants and Crustaceans

Mallard, pintail, gadwall, shoveller, cinnamon teal, green-winged teal, redhead, lesser scaup, bufflehead, ring-necked, and ruddy ducks nest in shoreline vegetation where the cover conceals them. In the breeding ground surveys, which have been conducted annually since 1949, as many as 682 nesting pairs of ducks have been observed. Seasonal, non-nesting visitors in this food group include the American widgeon, blue-winged teal, and common goldeneye.

Other Birds

Many birds not directly dependent upon Eagle Lake for their food use the lake's variable habitats or basin for nesting or during migration. Some of the more common birds that nest there are the Canada geese which nest on the islands; yellow-headed, red-winged, and Brewer's blackbirds which nest in the tule patches; and cliff, violet-green, and bank swallows which build nests in the rimrocks and sandy bluffs. Tree swallows nest in woodpecker excavations in the large trees bordering the lake. Killdeer and spotted sandpipers lay their eggs on pebble beaches and dry meadows.

Other birds that nest in the lake's basin and are part of the Eagle Lake biotic community include the turkey vulture, goshawk, sharp-shinned hawk, red-tailed hawk, sparrow hawk, blue grouse, sage grouse, mountain quail, Wilson's phalarope, common snipe, mourning dove, great horned owl, long-eared owl, spotted owl, poor-will, common nighthawk, red-shafted flicker, pileated woodpecker, white-headed woodpecker, western fly catcher, western wood pewee, steller's jay, scrub jay, mountain chickadee, red-breasted nuthatch, pygmy nuthatch, Townsend's solitare, yellow warbler, Audubon's warbler, western tanager, evening grosbeak, Oregon junco, chipping sparrow, and Brewer's sparrow.

Numerous birds use Eagle Lake Basin during their migrations. These include the Swainson's hawk, prairie falcon, peregrine falcon, snowy egret, sora rail, black-necked stilt, long-billed curlew, whimbrel, greater yellowlegs, northern phalarope, band-tailed pigeon, purple martin, Clark's nutcracker and black-capped chickadee. One additional member of this group is the sandhill crane which feeds in the meadows adjacent to Willow Creek.

Management

The U. S. Forest Service and the California Department of Fish and Game have undertaken a program to protect the osprey and improve its nesting habitat at Eagle Lake. Two major problems confronting these birds are the deterioration of snags that are used for nesting, and disturbance of the birds by recreationists. The present management plan now under way involves the establishment of an osprey management area that will include the colony breeding ground along a portion of the west shore of Eagle Lake. The U. S. Forest Service has improved the osprey nesting habitat by placing 20 cedar poles and topping 16 trees. The public has been informed of this program through various news media. A part of the plan yet to be accomplished will provide observation points and trails so the public can view the osprey nests.

Osprey Nest Near Eagle Lake

Ospreys prefer a large tree that has a broken top and side limb support with a pilot tree nearby for resting.

Trees Killed by High Water Levels

These trees along the Eagle Lake shoreline died after being inundated in 1916, the year the lake reached its highest recorded elevation (5125 feet). When this photograph was taken in 1921, the lake surface elevation was down to about 5119 feet.

Note the osprey approaching its nest at the top of the large tree.

CHAPTER III. SHORELINE DEVELOPMENT

In 1972 the permanent population at Eagle Lake was only 14 families comprising 34 persons. However, the lake is a rapidly developing summer resort and recreational area. Evidence of this is shown by the increasing numbers of campers, summer homesites, airplanes, boats, and boat ramps around the lake. The Lassen County General Plan indicates that recreation and tourism represent the best long-term use of Eagle Lake.

Recreation

Annual recreation use was only a few thousand visitors in the 1950s. By 1962 it had increased to about 50,000 visitors per year. Current recreation use is estimated at about 180,000 recreation-days annually. Fishing is a major recreation activity but many people also visit Eagle Lake to camp, hike, hunt, view the abundant bird life and the unusual scenery, and enjoy the relative solitude. The lake is used extensively for boating, waterskiing, and swimming.

There are four summer home tracts, five campgrounds, two major and seven minor marinas, and two airports at Eagle Lake. A summary of the recreation facilities and estimated use is given in Table 1. Plate 1 shows the general location of major developments around the lake.

Camp and Picnic Grounds

At present the U. S. Forest Service has developed three campgrounds and two picnic grounds at the south end of the lake. There is a total of 287 campsites developed. Prior to 1972 considerable camping was also done at the Circus Grounds area. This was closed to overnight camping beginning January 1, 1972; however, there are plans to develop a 50-unit campground in the area when funds permit.

The Bureau of Land Management has a 17-campsite campground located on the north end of Eagle Lake near State Highway 139.

Marinas

The principal marina at Eagle Lake is located on the south shore near Gallatin Beach. This facility is owned by Lassen County, built on Forest Service land, and operated by a private concessionaire. The marina supplies launching facilities, food, fuel, and sundries. The other major marina is the Stones Landing Boat Launch in the Stone Subdivision. It was built in 1963 by the California Wildlife Conservation Board and is located on county property and maintained by the county. Sanitary facilities are the only improvements that presently exist at this launching area. Several other minor boat launching areas are located around the lake. Launching areas are created each year at Gallatin Beach, the

TABLE 1

SUMMARY OF MAJOR RECREATION FACILITIES
AND ESTIMATED RECREATION USE AT EAGLE LAKE [1]

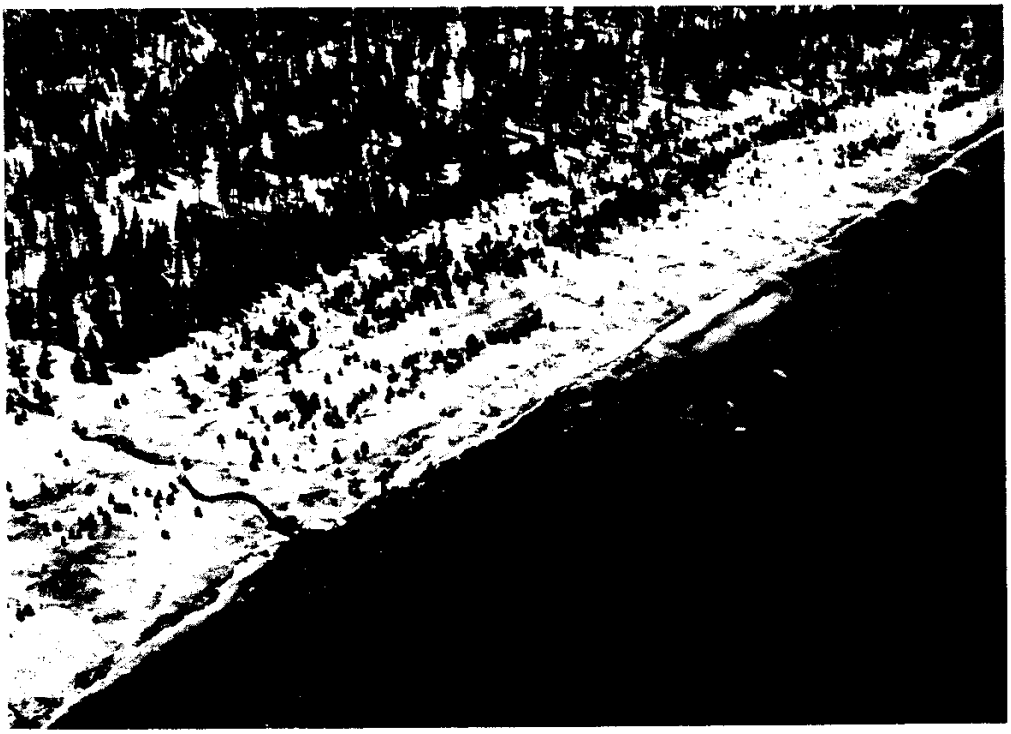
Area	Facilities	Annual Recreation Days [2]	Operating Agency
Aspen Grove Campground	31 Campsites	9,000	USFS
Eagle Campground	49 Campsites	15,000	USFS
Merrill Campground	207 Campsites	42,000	USFS
Gallatin Beach Picnic Area	30 Picnic Sites	25,000	USFS
Bureau of Land Management Campground	17 Campsites	3,500	BLM
Circus Grounds Area (Christie Beach)	Undeveloped [3]	25,000	USFS
Eagle Lake Marina	Boat Ramp and Marina	18,000	Lassen County
Eagle Lake Public Fishing Access (Stones Landing)	Boat Ramp	1,000	Lassen County
State Highway 139	Undeveloped	14,000	Division of Highways
Lassen County Route A-1	Undeveloped	2,000	Lassen County
Recreation Residences			
Eagles Nest	42 Cabins	7,500	USGS
Spalding Tract	60 Cabins	11,000	Private
Stones and Bengard Subdivisions	32 Cabins	6,000	Private
TOTAL		179,000	

1/ Based on U. S. Forest Service (USFS) data for 1967 through 1971 and estimates for other facilities.

2/ The USFS reports recreation use in visitor-days. A visitor-day is one person spending 12 hours in a campground, or 12 people using an area for 1 hour, or any similar combination. A recreation-day is use by one person for 1 day or any significant part of a day. It may be as brief as 1 hour or as long as 24 hours. The use estimates summarized above have been converted from 12-hour visitor-days to recreation-days to conform to the unit of use normally used by the Department of Parks and Recreation.

3/ Closed to overnight camping beginning January 1, 1972. USFS plans to develop a 50-unit campground when funds permit.

Eagle Lake Marina and Gallatin Beach on the South Shore



Merrill Campground at the South End of the Lake

Eagle Lake Marina, the Merrill Campground, and the Circus Grounds. In addition there are three launching areas at Spalding Tract. To minimize the adverse impact of boat launching on nesting birds in the Spalding Tract area, the three launching areas will be consolidated into one.

Summer Homes

Three summer home tracts have been developed around Eagle Lake. The Spalding Tract, located on the west shore near Pelican Point, is a 508-acre area originally subdivided in 1924 into 5,960 lots. Because of septic tank drainage difficulties, building parcels must consist of at least 4 to 6 lots. The maximum capacity of the subdivision is therefore approximately 1,200 building parcels. Only 60 cabins have been built, leaving the subdivision 95 percent vacant of permanent structures. The Stone and Bengard Subdivisions are located on the northwest shore of the lake. They use a relatively narrow 220-acre strip on the lake frontage. In 1968 the Lassen County General Plan reported 28 cabins constructed and 83 percent of the lots vacant. The Eagle Nest Tract is a 42-lot summer home tract located on leased Forest Service land just north of Gallatin Beach on the south shore. Cabins have been built on all 42 lots.

Other Development

With the exception of the Chico State Biological Station, most other development at the lake has been for the purpose of providing access to the recreation facilities.

Roads and Highways

The two principal roads near the lake include the Eagle Lake Road (Lassen County Road A-1) and State Route 139. The Eagle Lake Road is paved from Susanville to the Eagle Lake Marina and along the south shore. From there it continues around the west side of the lake as a gravel road joining State Route 139 at the north end. For most of its route it is a considerable distance from the lake.

State Route 139 is the principal route from Susanville to Adin. It skirts the lake on the northeast edge for approximately 5 miles. Large sections of it are located at only a few feet above the present elevation at the lake and are subject to wave-wash damage from the lake and from ice being pushed across the road during the spring of the year. A considerable amount of rock revetment has been placed along this section of the road for protection from wave damage. In 1970 a section was relocated to a higher elevation because of inundation. The current elevation of the low portions is approximately 5,111 feet.

Airports

Two airports are located near Eagle Lake. The Glenn Airport, located at the south end of the lake, is privately maintained but open to the public.

The Spalding Tract Airport is a 5,300-foot dirt runway located near the Spalding Tract. It is owned by Lassen County and leased to a private operator. Its elevation of approximately 5,115 feet makes it subject to inundation if the lake continues to rise. Considerable concern has been expressed about the effect of airplanes in this area on the large nesting colony of grebes nearby.

Chico State Biological Station

The Chico State Biological Station was founded in 1945 as a research and teaching facility. It was located on Eagle Lake to take advantage of the many unique forms of plant and fish life found at the lake. In addition to being used by Chico State University, several high schools use the facilities for biological study.

The facility is used only during the summer when the road is passable. Summer classes are conducted for about 30 students of the University and research work is pursued by professors and graduate students. Most work is done by students as a class project or as a requirement for a master's thesis. Currently, faculty members are conducting a research effort towards developing a nutrient budget of the lake.

Spalding Tract Area on the West Shore of Eagle Lake. Pine Creek estuary can be seen in the upper center of the photograph.

CHAPTER IV. HYDROLOGY AND WATER QUALITY

Eagle Lake is a unique body of water. Unusual characteristics include its location at a relatively high elevation, the contrasting topography and vegetation surrounding the lake, and the relative clarity and purity of the water for a closed basin reservoir. Although it is a large body of water, a very delicate hydrological and ecological balance exists which must continue if its beauty and resources are to be preserved. This chapter discusses the water supply and quality conditions of the lake.

Water Supply

The watershed tributary to Eagle Lake contains approximately 435 square miles. Precipitation over this watershed with its subsequent surface and underground runoff provides the water supply to the lake.

Several estimates of the hydrology of Eagle Lake have been made in recent years, including a study by Professor S. T. Harding in 1965, and one made by the Department of Water Resources in 1961. New basic data on rainfall and lake elevations gathered since that time have pointed out some inconsistencies in these studies; therefore, new water supply estimates were made for this investigation.

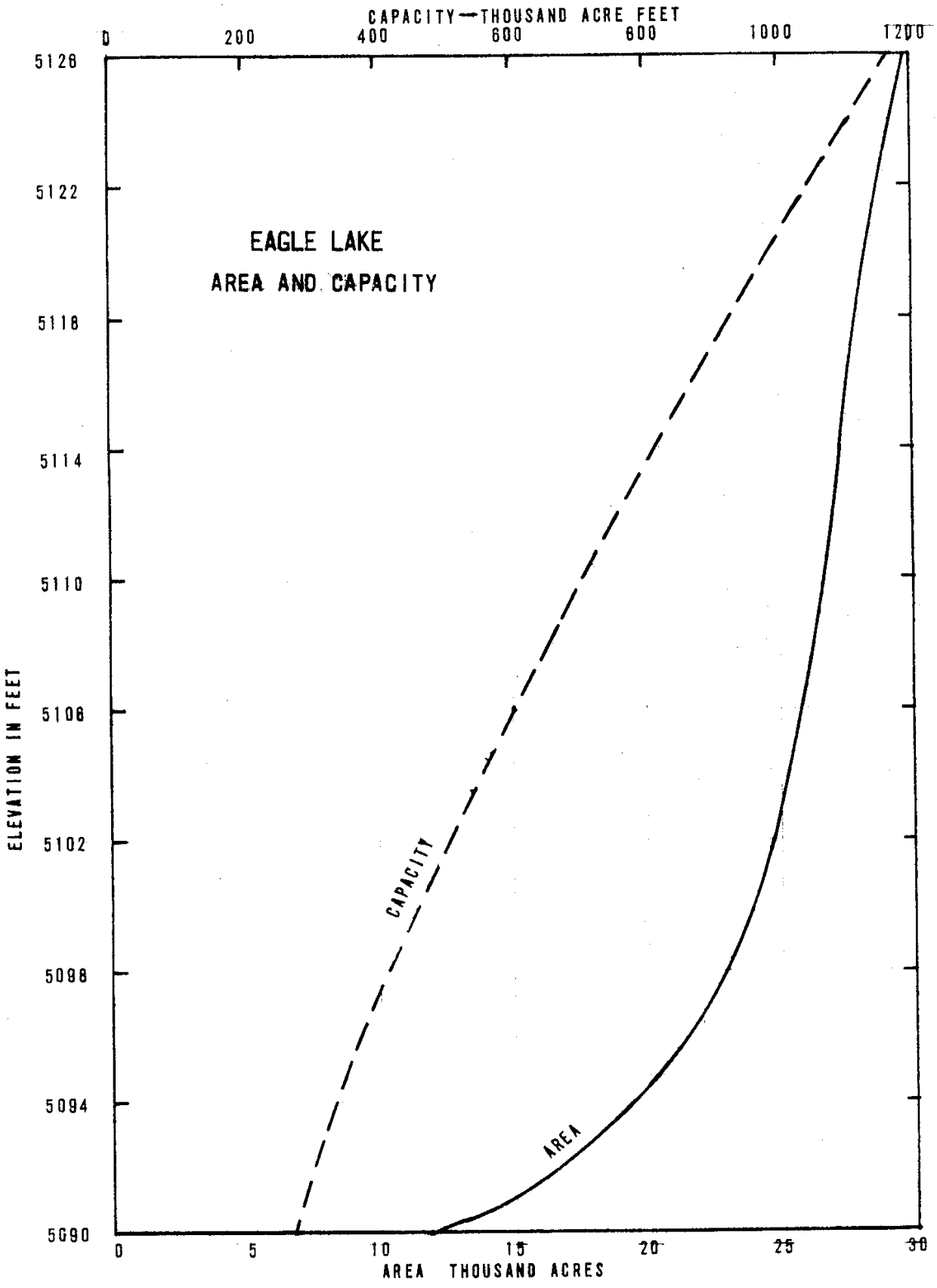
Lake Area and Capacity

The first curves showing surface area and storage capacity at various elevations were prepared by J. B. Lippencott, an engineer for the Tule Irrigation District. These were prepared in 1926 and used data gathered by Leon Bly prior to construction of the tunnel. More complete soundings of the lake were undertaken by the Department of Fish and Game in 1961. Unfortunately, the lake was at a low elevation at this time and the data are only good below elevation 5,100 feet. Curves above elevation 5,100 are still based on data gathered by Leon Bly. Figure 1 shows the area and capacity curves used in this study.

Precipitation

Few data are available showing rainfall at Eagle Lake or within the Eagle Lake watershed. However, data available show that the rainfall amounts vary widely over the drainage to the lake. The average annual precipitation on the westernmost portion of the drainage is near 40 inches, while on the easternmost portion it is only about 12 inches. On the lake surface the average annual precipitation varies from about 12 to 24 inches. The estimated average annual precipitation over the lake surface is about 18 inches. This was determined by using data from a precipitation station located at Spalding Tract from 1959 through 1969. This station was assumed to represent the average rainfall over the entire lake surface. Records from the station were correlated with data gathered at Susanville and at Susanville Airport to estimate the historic precipitation used herein.

FIGURE 1


CAPACITY—THOUSAND ACRE FEET
0
200
400
600
800
1000
1200
5126
5122
5118
5114
5110
5106
5102
5098
5094
5090
EAGLE LAKE
AREA AND CAPACITY
CAPACITY
AREA
ELEVATION IN FEET
0
5
10
15
20
25
30
AREA THOUSAND ACRES

Evaporation

Professor S. T. Harding estimated that the average gross annual evaporation from the lake's surface is 42 inches per year. This value is reasonable and was used in this study. For purposes of this study the net evaporation is assumed to be gross evaporation less annual precipitation over the lake's surface. No attempt was made to correct for evapotranspiration by plants along the lake edge which use water from the lake. Also, no attempt was made to determine monthly values of precipitation or evaporation. Figure 2 shows the estimated annual evaporation rate from the lake for the 96-year period, 1875-1970. The average annual net evaporation for the period is 24 inches per year. Estimates prior to 1912 are by S. T. Harding.

Inflow

Water enters Eagle Lake three different ways and leaves three different ways. Water enters the lake by surface inflow, primarily from Pine, Papoose, and Merrill Creeks; direct precipitation on the lake surface; and ground water inflow through springs beneath the lake. Water leaves the lake by evaporation, ground water outflow, and diversions or leakage through Eagle Lake Tunnel.

Of the six individual parameters involved in inflow and outflow from the lake, estimates have been made only for evaporation, tunnel flow, and precipitation. In computing available water supply, therefore, surface inflow, ground water inflow, and ground water outflow were combined to give a net inflow to the lake. This supply, over a long period of time, will approximate evaporation plus tunnel diversions. This assumes that the tunnel has no measurable effect on ground water outflow from the lake.

Several measurements have been made since 1959 of the discharge from the tunnel. These have been plotted in Figure 3 to show the relationship between lake elevation and tunnel outflow. It is assumed that essentially all water being discharged from the tunnel is derived from Eagle Lake. Streamflow measurements taken throughout the length of the tunnel support this assumption. Flow measurements made approximately 1 mile in from the tunnel outlet portal have indicated as much flow at that point as measurements made at the discharge portal.

Steps taken to estimate historic water supply to the lake are described below:

1. Reliable records of water stages of the lake are available for the periods 1914-1923 and 1948-1970. For these periods the annual net inflow to the lake was estimated from the volumetric change in lake storage by deducting the estimated net evaporation and tunnel outflow.

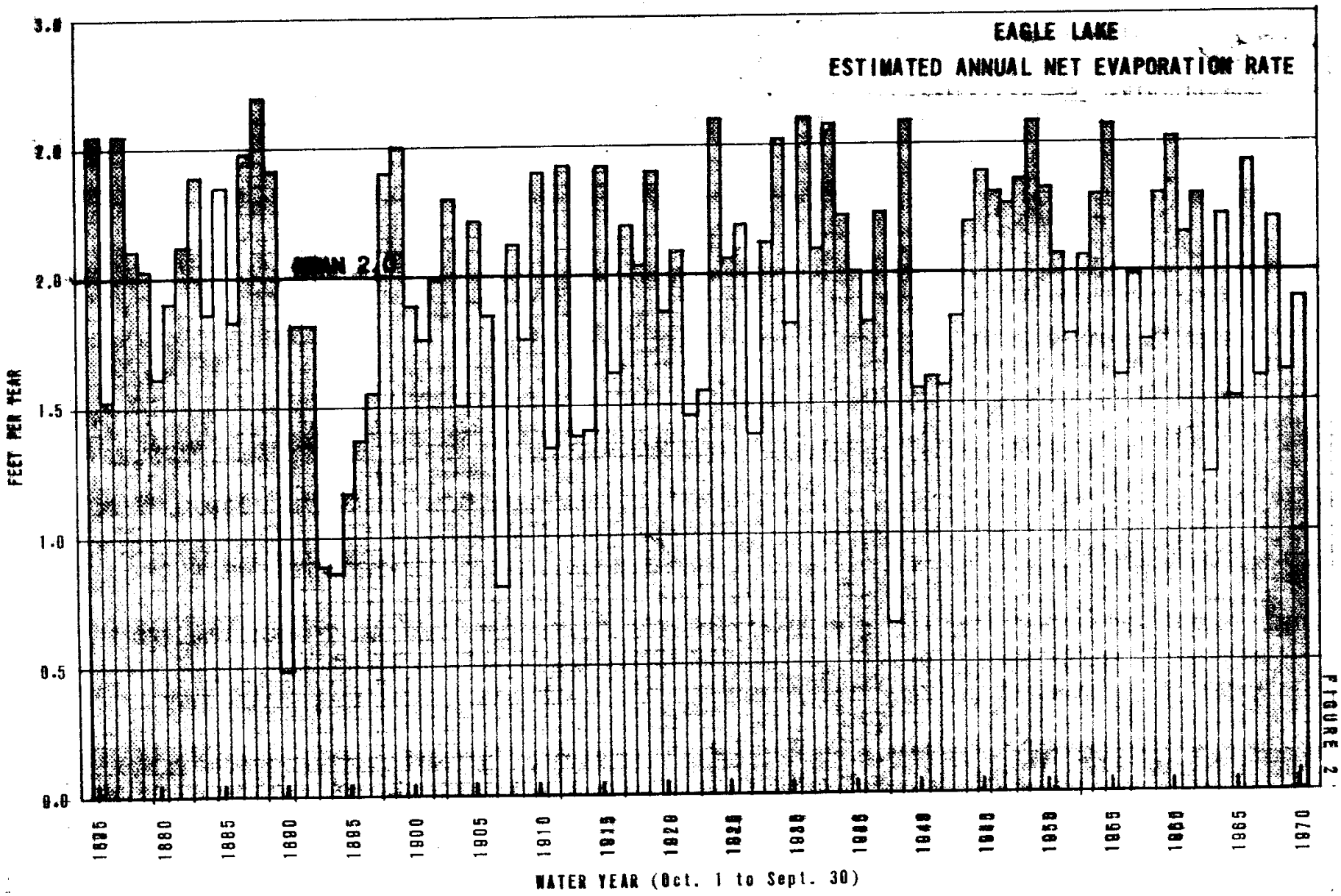

EAGLE LAKE
ESTIMATED ANNUAL NET EVAPORATION RATE
MEAN 2.0
FEET PER YEAR
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1875
1880
1885
1890
1895
1900
1905
1910
1915
1920
1925
1930
1935
1940
1945
1950
1955
1960
1965
1970
WATER YEAR (Oct. 1 to Sept. 30)

FIGURE 2

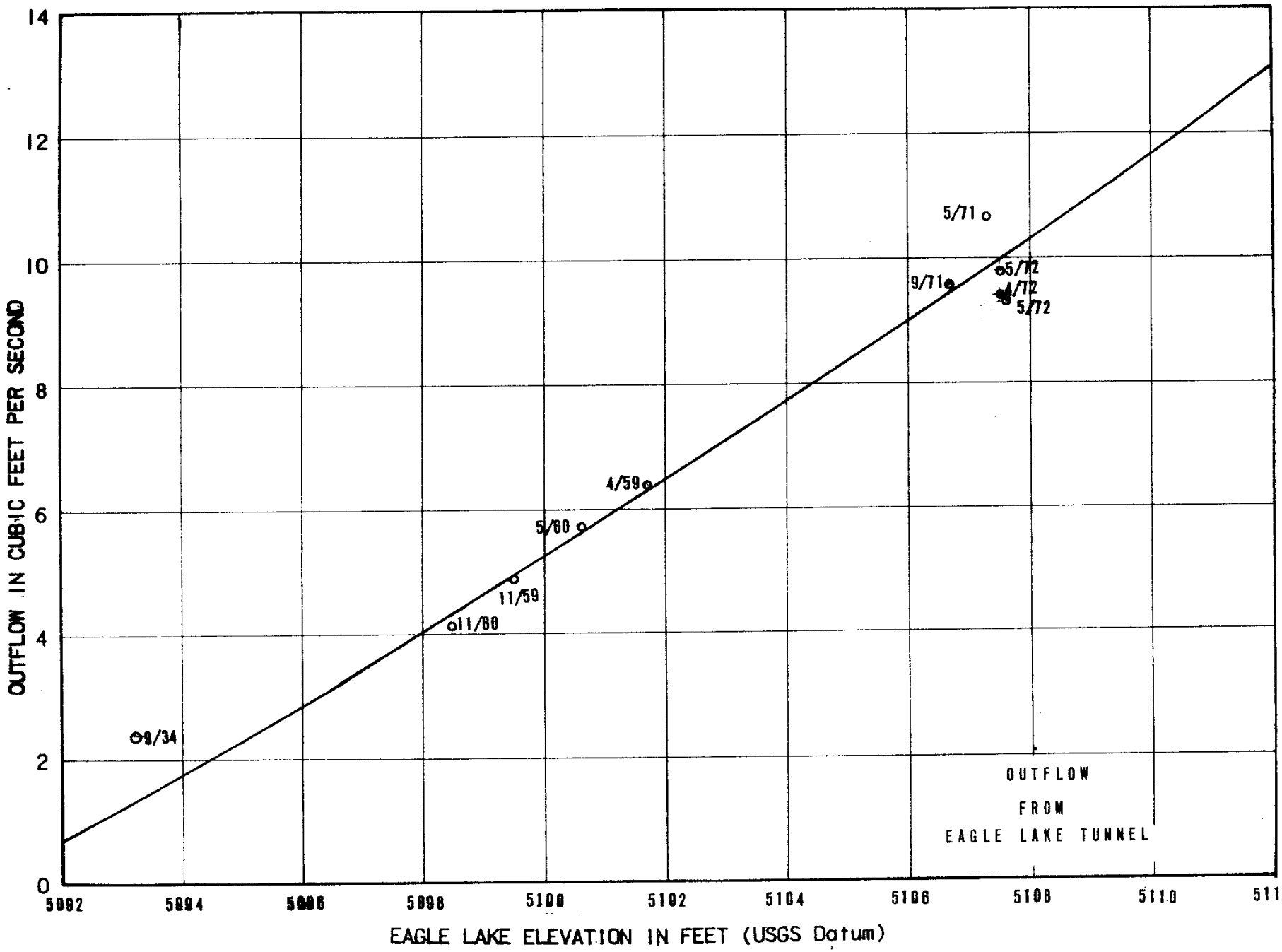

OUTFLOW IN CUBIC FEET PER SECOND
0
2
4
6
8
10
12
14
5092
5094
5096
5098
5100
5102
5104
5106
5108
5110
5112
EAGLE LAKE ELEVATION IN FEET (USGS Datum)
9/34
11/60
11/59
5/60
4/59
9/71
5/71
5/72
4/72
5/72
OUTFLOW
FROM
EAGLE LAKE TUNNEL

FIGURE 3

2. The computed and adjusted net inflow values for the 1914-1923 and 1948-1970 periods were correlated with the annual recorded runoff of Spanish Creek near Keddie. From this correlation the water supply for the period 1923-1936 was estimated.

3. For the period 1936-1947 net inflow values were determined by adjusting values from correlation with Spanish Creek to meet actual recorded lake elevations where they were available.

4. For the period 1875-1911 the values computed by S. T. Harding and published in "Recent Variations in the Water Supply of the Western Great Basin" were used.

The estimated annual net water supply to the lake for the 96-year period 1875-1970 is shown in Figure 4. The mean supply for this period is 52,400 acre-feet per year.

Water Quality

Eagle Lake can be considered as three lakes, connected by channels, that have different physical and biological characteristics. The north basin has a fairly uniform depth of about 14 feet with the water surface elevation at about 5,107 feet. It has no appreciable surface inflow. The middle basin has an average depth approximately the same as the north basin and is influenced by the runoff from Pine Creek, which is the major source of surface inflow to the lake. The south basin is the deepest, with an average current depth of about 50 feet, and has a relatively small inflow from Merrill and Papoose Creeks. The south basin is the only portion of the lake that stratifies during the summer. Stratification is the layering of water based on temperature-induced density differences. Frequent strong winds, predominantly parallel to the long axis of the lake, cause the seasonal stratification to occur later than most other lakes at this latitude and elevation. Stratification is at a relatively great depth in the south basin and does not occur in the middle and north basins. The winds do not tend to circulate much water from one basin to another because the channels between the basins are at an angle relative to the lake's long axis. The seasonal nature of inflow and summer evaporation result in a fluctuating lake level and variation in chemical characteristics.

Surface Inflow Water Quality

Inflow to Eagle Lake comes from Pine Creek, the major source of surface inflow; two minor streams, Papoose and Merrill Creeks; and several intermittent rivulets. Historic water quality data are not available for the surface tributaries, and only limited analyses were performed during this investigation. Based on this current information, the incoming waters to Eagle Lake are of excellent mineral quality. The concentrations of dissolved solids, chlorides, nitrates, and sulfates are low and the waters are generally of a magnesium-calcium bicarbonate

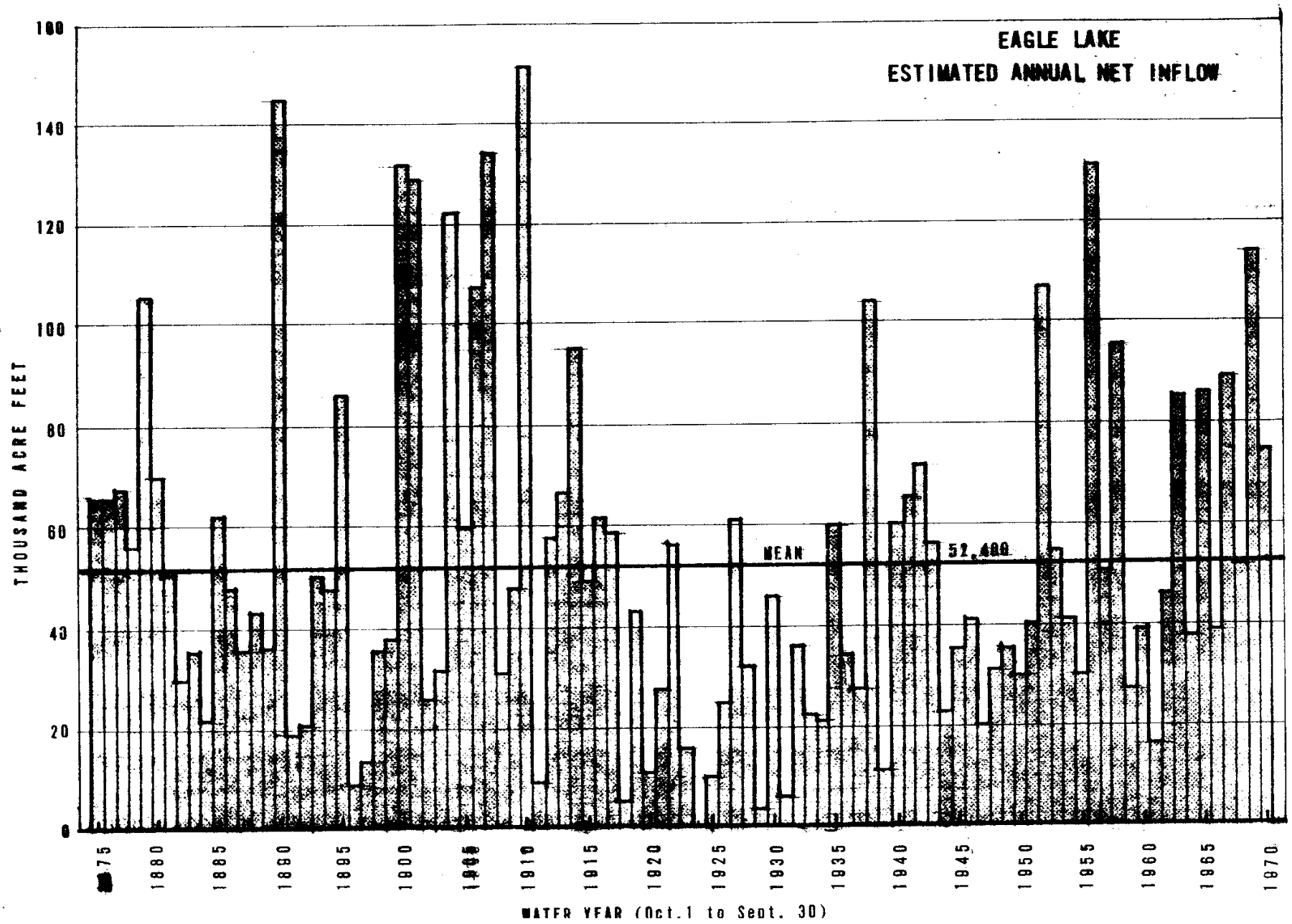

EAGLE LAKE
ESTIMATED ANNUAL NET INFLOW
THOUSAND ACRE FEET
160
140
120
100
80
60
40
20
0
MEAN
52,400
1880
1885
1890
1895
1900
1910
1915
1920
1925
1930
1935
1940
1945
1950
1955
1960
1965
1970
WATER YEAR (Oct.1 to Sept. 30)

FIGURE 4

type. The lake water in this area is diluted, as evidenced by a significantly lower concentration of dissolved solids in the samples taken in the Pine Creek arm of the lake during the seasonal runoff period.

The average characteristics found to exist for the Eagle Lake inflows during the spring of 1972 are summarized below:

Drainage	Temperature °F	pH	Specific Conductance Micromhos/cm	Turbidity JTU Units	Alkalinity mg/l CAO_3
Pine Creek	49	7.8	53	16	25
Merrill Creek	50	7.2	74	10	35
Papoose Creek	50	7.5	138	5	50
Minor Drainages	46	8.0	112	5	-

Ground Water Quality

Ground water movement into the lake is presently undefined; however, springs exist in several areas of the lake. A limited number of wells located around Eagle Lake were sampled during the spring of 1972. The samples indicate that the ground waters are all bicarbonate in character and are low in dissolved solids and nutrients. A well, located at the U. S. Bureau of Land Management campground on the north shore of the lake, indicates a sodium-calcium bicarbonate type water and a well located at the U. S. Forest Service Eagle Campground on the south shore indicates a magnesium bicarbonate type water. The average characteristics of the ground water is indicated by the 1972 samples are summarized below:

Well Location	pH	Specific Conductance Micromhos/cm	Alkalinity mg/l $CaCO_3$
BLM Campground	8.1	168	90
Spalding Tract	7.2	195	105
Eagle Campground	7.6	300	130

Springs located in the northern end of Willow Creek Valley near the headwaters of Willow Creek have been suggested to be seepages from Eagle Lake. A comparison of the Eagle Lake water and these spring waters show the waters to be similar in character, but significantly lower in concentrations of dissolved contituents. The lower concentrations in the spring waters are, however, similar to those found in Eagle Lake Basin. Based on the limited water analyses, the ground water and spring water are not only both bicarbonate-type waters, but have alkalinity and dissolved solid concentrations of the same magnitude.

Although the Eagle Lake tunnel inlet has been blocked by a debris fill, lake water seeps into the tunnel through this fill and fissures in the rocks. The flow in the tunnel varies with the water surface elevation in Eagle Lake since increased pressure forces more water into the tunnel.

Flow measurements taken in the tunnel during March 1972 show a flow of about 2 cubic feet per second immediately inside the entrance, about 7 cfs 250 feet inside the entrance, about 9.5 cfs 2,000 feet inside, and 9.5 cfs again at the outlet. The water leaving the tunnel has similar quality characteristics to the Eagle Lake water; however, the alkalinity and dissolved solids are slightly less.

Lake Water Quality

Historic water quality data for Eagle Lake prior to 1969 are limited to a few water analyses performed on samples taken periodically from 1952 to 1969 on a random basis in the lake and tunnel. In 1962, a complete survey of the lake was conducted by the Department of Water Resources, and in 1969 a limnology program was initiated whereby samples were taken periodically at specific stations on the lake. Plate 1 shows the location of the limnology stations currently monitored by the Department of Water Resources and the U. S. Forest Service.

The present water quality of Eagle Lake can be described as a sodium bicarbonate type of water that is slightly alkaline and moderately hard. The average limnological characteristics of Eagle Lake are listed below. Characteristics of other Northern California lakes are also listed for comparison.

Lake	Alkalinity mg/l $CaCO_3$	Hardness mg/l $CaCO_3$	pH	Specific Conductance Micromhos/cm	Secchi Disc Visibility (m)
Eagle	460	175	9.0	780	4 - 8
Tahoe	40	32	8.1	93	12 - 35
Goose	700	45	9.2	2,000	0 - 1
Shasta	45	42	7.3	112	3 - 6

Table 2 shows complete water analyses for various sources in the Eagle Lake Basin as well as the springs located near the headwaters of Willow Creek. The analyses are not intended to reflect average conditions on specific dates, but rather to compare the general water quality differences that exist for each source.

The average concentration of total dissolved solids in Eagle Lake has decreased from about 655 ppm in 1952 when the storage was 380,000 acre-feet to about 520 ppm in 1969 with a storage of 558,000 acre-feet. The concentration of dissolved solids appears to fluctuate with the lake storage as indicated by test results over the past 20 years. Some salt removal is evidenced by the white precipitate that is visible on the rocks along the shoreline as the lake level drops. Some additional salts are removed by the uptake of salts by the fresh water snails and various aquatic plants that are abundant in the lake.

Historic nutrient data are not available for Eagle Lake prior to 1971. Based on samples collected during 1971 lake surveys, the

TABLE 2

MINERAL ANALYSES OF SURFACE AND GROUND WATER

EAGLE LAKE BASIN AND WILLOW CREEK

LASSEN COUNTY

Source	Location	Date sampled	Discharge in cfs	Temp in °F	Specific conductance (micromhos at 25°C)	pH	Mineral constituents in parts per million / equivalents per million: Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Carbonate (CO_3)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Nitrate (NO_3)	Fluoride (F)	Boron (B)	Silica (SiO_2)	Other constituents	Total dissolved solids in ppm	Percent sodium	Hardness as $CaCO_3$: Total ppm	Hardness as $CaCO_3$: N.C. ppm	Remarks
Surface Inflow	Pine Creek	4-27-71	218	45	62	8.0	4.2 / 0.21	3.5 / 0.29	2.4 / 0.10	1.0 / 0.03	0.0 / 0.00	33 / 0.54	2.3 / 0.05	0.0 / 0.00	0.1 / 0.00		0.0			58	16	25	0	
Surface Inflow	Merrill Creek	4- 6-72	-	50	60	7.3	5 / 0.25	3.8 / 0.32	1.9 / 0.08	0.6 / 0.02	0.0 / 0.00	37 / 0.61	0.0 / 0.00	0.0 / 0.00	0.0 / 0.00		0.0			70	12	28	0	
Surface Inflow	Papoose Creek	3-10-72	-	52	92	7.3	9 / 0.45	3.7 / 0.31	3.9 / 0.17	1.1 / 0.03	0.0 / 0.00	55 / 0.90	0.5 / 0.01	0.0 / 0.00	0.2 / 0.00		0.0			53	18	38	0	
Ground Water	B.L.M. Campground	3-10-72		-	181	7.9	13 / 0.64	5.2 / 0.42	18 / 0.78	3.6 / 0.09	0.0 / 0.00	108 / 1.77	0.8 / 0.02	1.9 / 0.05	1.1 / 0.03		0.0			95	40	54	0	
Ground Water	Eagle Campground	3-10-72		-	312	8.0	13 / 0.66	20 / 1.64	14 / 0.61	3.7 / 0.09	0.0 / 0.00	155 / 2.54	0.0 / 0.00	2 / 0.06	0.0 / 0.00		0.0			119	20	115	0	
Willow Creek Springs	Murrers Upper Meadow	3- 9-72		68	191	7.9	11 / 0.54	6.4 / 0.52	19 / 0.83	3.8 / 0.10	0.0 / 0.00	114 / 1.87	0.3 / 0.01	2.0 / 0.06	1.5 / 0.04		0.0			103	42	53	0	
Willow Creek Springs	Willow Creek Spring	3- 9-72		60	213	7.9	12 / 0.62	9 / 0.74	19 / 0.83	4.7 / 0.12	0.0 / 0.00	131 / 2.15	0.0 / 0.00	0.8 / 0.02	0.6 / 0.01		0.0			110	36	68	0	
Eagle Lake	Tunnel Outlet	9-10-52	-	-	940	8.1	28 / 1.40	37 / 3.04	144 / 6.26	17 / 0.43	0.0 / 0.00	620 / 10.16	1.6 / 0.03	18 / 0.51	4 / 0.06	0.0 / 0.00	0.17	21		576	56	222	0	
Eagle Lake	Tunnel Outlet	4-24-57	6.5	63	917	7.8	25 / 1.25	36 / 2.99	140 / 6.09	19 / 0.49	0.0 / 0.00	617 / 10.11	0.0 / 0.00	16 / 0.45	1.2 / 0.02	0.1 / 0.01	0.01	22		562	56	212	0	
Eagle Lake	North Basin	5- 4-54		83	1,330	8.8	4.5 / 0.22	49 / 4.03	220 / 9.57	59 / 1.51	55 / 1.83	758 / 12.42	1.6 / 0.03	22 / 0.62	2.2 / 0.04	7.0 / 0.37	0.03	10		804	62	213	0	
Eagle Lake	North Basin	8-29-62		70	1,240	9.2	10 / 0.50	51 / 4.20	209 / 9.09	53 / 1.36	135 / 4.50	604 / 9.90	0.0 / 0.00	23 / 0.65	0.5 / 0.01	0.2 / 0.01	0.08	16		850	60	235	0	2' Depth
Eagle Lake	North Basin	4-25-71		46	819	9.0	9 / 0.45	40 / 3.29	115 / 5.00	30 / 0.77	6 / 0.20	545 / 8.93	1.3 / 0.04	13 / 0.37	0.0 / 0.00	-	0.1	-		493	52	187	0	3' Depth
Eagle Lake	Middle Basin	1956		-	903	8.6	11.2 / 0.56	36.3 / 3.04	124 / 5.40	35.9 / 0.92	20.1 / 0.67	530 / 8.69	Trace	27.7 / 0.78	-	0.1 / 0.01	0.09	-		509	54	-		
Eagle Lake	Middle Basin	8-29-62		68	1,150	9.1	31 / 1.55	36 / 2.99	186 / 8.09	49 / 1.25	108 / 3.60	589 / 9.65	0.0 / 0.00	21 / 0.59	0.8 / 0.01	0.1 / 0.00	0.08	18		780	58	227	0	2' Depth
Eagle Lake	Middle Basin	4-25-71		46	756	8.9	7.4 / 0.37	37 / 3.05	106 / 4.61	27 / 0.69	0.0 / 0.00	506 / 8.29	2.0 / 0.04	13 / 0.37	0.0 / 0.00	-	0.1	-		451	53	171	0	Surf. Sample
Eagle Lake	South Basin	7-11-52		-	1,040	9.2	11 / 0.55	39 / 3.21	174 / 7.57	48 / 1.23	81 / 2.70	548 / 8.98	1.0 / 0.02	21 / 0.59	0.1 / 0.00	0.0 / 0.00	0.1	16		661	60	188	0	
Eagle Lake	South Basin	8-29-62		66	1,050	9.2	11 / 0.55	45 / 3.73	163 / 7.09	43 / 1.10	67 / 2.23	589 / 9.65	0.0 / 0.00	19 / 0.54	0.7 / 0.01	0.2 / 0.01	0.07	18		685	57	214	0	2' Depth
Eagle Lake	South Basin	4-26-71		45	805	8.8	8.2 / 0.41	39 / 3.17	113 / 4.92	29 / 0.74	0.0 / 0.00	540 / 8.86	1.6 / 0.03	13 / 0.37	1.0 / 0.02	-	0.1	-		468	53	179	0	29' Depth

average concentration of nutrients found to exist for each basin of the lake are listed below:

	Phosphorus (ppm)		Nitrogen (ppm)		
	Ortho Phosphate	Total Phosphorus	Organic Nitrogen	Ammonia	Nitrate
North Basin	0.00	0.03	0.9	0.00	0.00
Middle Basin	0.00	0.03	0.9	0.01	0.02
South Basin	0.01	0.05	1.0	0.06	0.01

The nutrient concentrations are considered to be low to moderate but support a relatively high plankton growth and the excellent fishery in Eagle Lake. The greatest portion of the nutrients are in organic form which indicates that dissolved forms are being used by biological organisms.

The south basin of the lake appears to have a higher production of algae and plankton than the middle and north basins. Generally, summer algae blooms occur in the south basin while the other two basins are relatively clear. This occurs even though the middle and north basins appear to be more favorable for algae growth due to the shallow warmer waters and the lack of stratification. The south basin may be subject to more efficient recycling of nutrients or have an additional source of nutrients from ground water. The nutrient production of the lake is currently being evaluated by personnel from Chico State University.

CHAPTER V. ALTERNATIVE OPERATIONAL PLANS

It has been suggested that since Eagle Lake lies within a closed basin, the best protection of the lake's environment would be to let the lake seek its natural level by stopping all outflow. This, it is argued, would allow all the unique biological features of the lake to continue to live in the ecosystem where they were created. However, man's activities have now become part of the lake's system, and the impact that man has had and will continue to have on this system must be considered. Others theorize that some outflow is necessary to control the salt and nutrient levels, thereby slowing down eutrophication of the lake. Still others say that the lake's elevation should be controlled at some maximum elevation to prevent inundation of beaches and loss of property along the lakeshore.

The purpose of this investigation was to evaluate alternative actions that could be taken to preserve or enhance Eagle Lake and its surroundings. Four specific operational alternatives were evaluated and compared. Several other possible alternatives were considered but were rejected because of obvious undesirable effects or similarity to one of the alternatives discussed in this report. As an example, consideration was given to construction of a dike across the lake from Little Troxal Point to Rocky Point. This physical separation would allow essential stabilization of the north portion of the lake while the south portion would return to a normal fluctuation. This possibility presents obvious problems primarily in the area of fish migrations, undesirable esthetics and restricted boating, and was dropped before complete evaluation was made.

Description of Alternatives

The following sections describe the four alternatives which were evaluated.

Alternative No. 1 (Seal the Tunnel Completely)

This alternative involves the complete sealing of the Eagle Lake Tunnel, thereby allowing the lake to return to natural conditions of fluctuation with inflow, evaporation, and an unknown amount of subsurface outflow controlling lake elevations.

Several methods of sealing the abandoned tunnel to completely stop flow were evaluated. One of the most important considerations in selecting a sealing method was accessibility of the location at which the plug would be placed. Two plug locations were considered and are shown on Plate 2. The one which appears to be the most feasible is located about 3,800 feet from the outlet portal. This location is not far from the old construction adit which could provide access for construction

of the plug. The other is located at the upstream end of the 60-inch corrugated metal pipe located about 360 feet inside the upstream portal.

A plug probably will not completely stop leakage. Therefore, in addition to placing a plug in the tunnel, a grout curtain would be required to limit the amount of leakage. The extent of the grout curtain is difficult to determine without more complete geologic information. As the hydrostatic head increases at the plug locations, some water will probably seep through fissures and reenter the tunnel below the plug. The entire tunnel is located in a basaltic rock formation which contains many fissures which allow leakage of water. This was evident during tunnel construction when leakage necessitated "holing out" at a much higher elevation than planned. It is difficult to estimate the amount of leakage that would occur. However, should severe seepage occur, it could be reduced by expanding the grout curtain.

Alternative No. 2 (Leave Tunnel As Is)

Under this alternative, leakage would continue in essentially the same manner that it has since 1937; that is, low leakage would occur at low lake elevations and higher leakage would occur at high elevations. This proposal has the advantages of continuing the Willow Creek fishery, providing supplemental irrigation water to Willow Creek users, and avoiding excessively high lake levels. It also involves very little cost.

Under this alternative some work would be necessary at the tunnel entrance. It would consist of filling that portion of the intake channel from the existing sand dike to the entrance portal to an elevation of about 5,120. This would prevent overtopping of the dike and reduce leakage slightly. Material for fill should be the most impervious available. Nearby tailings excavated from the tunnel are suggested as a good possibility.

Alternative No. 3 (Control Maximum Lake Level to 5,106 Feet)

This alternative would require sealing the tunnel; however, a control valve would be included whereby the lake elevation would be limited to a maximum of 5,106 feet except during years of exceptionally high runoff. This plan would protect all existing facilities around the lakeshore above an elevation of about 5,111 feet. It would not prevent the lake from receding to critically low elevations during drought periods.

The elevation of 5,106 feet was selected as the maximum lake level that could be maintained without inundating State Route 139, assuming the 100-year frequency inflow would occur when the lake is at its maximum controlled elevation. The 100-year inflow, which is estimated to be about 150,000 acre-feet in 1 year, would raise the lake about 5 feet to elevation 5,111. Maximum annual releases from the tunnel under these conditions would be 60,000 acre-feet.

The construction necessary for this alternative would be similar to that required for Alternative No. 1 except that a control valve would

be placed in a pipe through the tunnel plug. Also, the tunnel entrance would be cleaned out and a trashrack placed across the opening to prevent debris from entering the tunnel.

Alternative No. 4 (Control Maximum Lake Level to 5,115 Feet)

This alternative is similar to Alternative No. 3 except that the lake elevation would be allowed to rise to elevation 5,115. Although this would not protect State Route 139 and other facilities from inundation, it would provide protection to most of the existing subdivisions and homesites.

Under this alternative, controlled releases would be made through the tunnel only during extremely wet periods. The main purpose would be to provide a guarantee that campgrounds, homes, and shoreline developments lying above 5,117 feet would be safe from inundation, and to provide a means whereby water could be released should it become desirable or necessary in the future to protect the quality of the lake. Elevation 5,117 is approximately the level the lake would reach if a 100-year frequency inflow should occur when the lake is at elevation 5,115.

Basis of Comparison

To compare the four alternatives, considerable information on the relative impact of each alternative on fish and wildlife resources, recreation development, water quality, and overall environment of the lake and its basin was gathered and analyzed. Possible legal ramifications for each alternative were also considered.

The method undertaken to compare alternatives was to establish a uniform set of base conditions at the lake and evaluate the relative effect each alternative would have on these conditions. Water supply to the lake was a primary consideration, since the lake's life and condition depends on the amount and quality of water flowing to and from the lake. It was assumed that the lake inflow over the past 96 years, from 1875 to 1970, was typical and that similar patterns would be repeated over the next 96 years. Estimated annual water supply and evaporation data for this period are discussed in Chapter IV.

Operation studies were made for each alternative evaluated. These studies determined the annual lake surface elevation and inflow-outflow over the selected period. Annual values determined were for October 1, which represents the approximate low water for each year. The high water for any year was from 1.5 to 2 feet higher than the October 1 elevation.

The hydrographs on Plate 3 show the actual lake elevations that have occurred over the study period and estimated lake elevations that would have existed under each of the alternatives considered.

The comparisons of each alternative are discussed in the following sections. These comparisons are based on the assumed hydrology discussed earlier in the report. Even though future water conditions may

differ considerably from those of the past, the relative impact of each alternative would probably be similar.

Effects on Lake Elevation

Average, maximum, and minimum lake elevations, reservoir storage, and surface areas for each alternative over the study period are shown in Table 3. The hydrographs shown in Plate 3 indicate that a difference of 5 feet would have existed between the actual elevation in 1970 and the estimated elevation the lake would have been had there been no diversion through the tunnel. Plate 3 shows that the difference in 1960 would also be 5 feet. Professor S. T. Harding's study indicated that only a 1-foot difference would have existed in 1960. The difference is attributable to improved hydrologic data and to the fact that the tunnel is leaking, a factor which Professor Harding's studies did not consider. Since better basic data are available now, the current studies should be more reliable.

TABLE 3

IMPACT OF ALTERNATIVES ON LAKE ELEVATION, SURFACE AREA, STORAGE, AND SPILL
(for 96-year period, 1875-1970)

Item	Actual	Operational Alternatives No. 1	No. 2	No. 3	No. 4
Elevation (October 1)					
Average	5,107	5,110	5,104	5,101	5,106
Maximum	5,125	5,125	5,116	5,108	5,117
Minimum	5,092	5,099	5,092	5,090	5,094
Surface Area (1,000 Acres)					
Average	25	27	24	24	25
Maximum	29	29	28	26	28
Minimum	16	23	15	12	20
Storage (1,000 Acre-feet)					
Average	640	733	568	508	627
Maximum	1,133	1,133	876	673	900
Minimum	316	447	312	287	354
Release or Spill (1,000 Acre-feet)					
Average (96-Year)	4	0	6	7	3
Maximum	55	0	12	60	60
Minimum	0	0	1	0	0

Effects on Water Quality

A salt balance study was conducted to help evaluate the impact on water quality of Eagle Lake under the alternative plans of operation. The study is based on a limited number of historic water analyses from 1952 to 1970. Consideration was given to all known major processes of salt input and removal, although the effect of some of these processes could not be estimated with a high level of confidence. Additional salt loadings caused by man's future development in the basin were not considered. The results, therefore, should only be considered for comparison of alternative operational plans and not as water quality forecasts.

Hydrologic Balance

The hydrologic balance of Eagle Lake involves the relationship between the various factors affecting the quantity of water in the lake. The primary factors are precipitation, evaporation and evapotranspiration, surface and ground water inflows and outflows, and net change in the storage of the lake. For this study, a simplified hydrologic balance was prepared on the basis of estimated quantities of evaporation, precipitation, and tunnel outflow. A more detailed discussion of hydrology is presented in Chapter IV.

The estimated average annual net inflow to the lake for the period 1875 to 1970 is 52,400 acre-feet. The average discharge of Pine Creek, based on recorded flows from 1960 to 1968 is approximately 11,400 acre-feet annually. Since Pine Creek drainage is the major source of surface inflow to the lake, it is evident that a substantial quantity of ground water inflow exists. To differentiate between surface and ground water inflows, it was assumed for this salt balance study that the net inflow would consist of 40 percent surface water and 60 percent ground water. No attempt was made to estimate ground water outflow.

Water Quality Balance

The mineral quality of water in Eagle Lake can be described by a water quality balance which compares quantities of dissolved material entering and leaving the lake each year. The quality and quantity of water from each source entering and leaving the lake are combined to produce the balance. The water quality indicator used for this study is the total dissolved solids, a relatively conservative constituent that includes all the salts in solution. A meaningful balance could not be run on the more conservative chloride ion due to its low level of concentration in Eagle Lake.

The estimated concentration of total dissolved solids entering the lake is 80 parts per million in surface water and 125 parts per million in ground water.

Eagle Lake is a closed basin lake with no natural outlet and essentially no surface outflow. The average salt input to the lake is estimated to be 7,000 tons per year based on the assumed values of ground

water inflow, surface water inflow, and concentrations of each. With this amount of salt entering the lake each year, and evaporation removing a considerable amount of pure water, it would appear that the water quality would have deteriorated and caused the lake to become brackish or saline. However, salt concentrations in the lake have historically not fluctuated a great deal. During the past 20 years (1950-1970) of above-normal runoff, salt concentrations have decreased slightly. It appears, therefore, that Eagle Lake is near an equilibrium condition. Since the average salt input from the inflowing waters exceeds that in the outflow by about 7,000 tons per year, it is apparent that salt removal processes are active within this system. These salt removal processes (salt sink) probably result from a combination of movement of water from the lake into the surrounding ground water body, biochemical and chemical precipitation, and biological uptake. Any one of these processes could account for a significant portion or all of the annual salt sink. Since each process varies with lake storage and quality, studies could not realistically be made with a fixed salt sink factor. Salt sinks were therefore computed on the basis of known water quality conditions between 1952 and 1970. These values indicated general relationships between the salt sink and lake storage and quality, which were assumed could be applied to other periods. Salt sink values determined from these relationships were then tested by computing Eagle Lake water quality for the 1875-1970 period. These results indicated that the assumed relationships were reasonable and could be used for comparison of alternatives.

Comparison of Alternatives

The actual historic water quality condition of the lake serves as the base from which the alternatives were compared. A salt concentration of 500 ppm in 1875 was assumed as the initial lake condition. This is an arbitrary estimate; however, it appears reasonable. Salt concentrations determined from salt balance studies for each alternative operational plan are shown in the following tabulation:

	Salt Concentrations (ppm) for Period 1875-1970				
Alternative	1875	1970	Average 1875-1970	Maximum	Minimum
Historic	500	500	490	750	300
No. 1	500	450	460	600	300
No. 2	500	450	470	750	300
No. 3	500	450	460	700	250
No. 4	500	500	490	750	300

The above values show there was little long-term change in salt concentrations as a result of the alternative operational plans.

Evaluation of Results

These salt balance studies were based on limited water quality data covering a relatively short period of time in a complex lake system.

The results are believed to provide a reasonable comparison as to the relative quality of water in Eagle Lake that would exist for each alternative under study. However, they should serve only as a guide to indicate potential relative trends rather than specific salt concentrations to be expected. These results should remain valid until such time that man's activities within the drainage area cause significant shifts in the character of Eagle Lake water quality or changes in the lake's ecosystem.

Studies to evaluate the effect the four alternatives would have on the nutrient levels of the lake would be extremely complex and were not within the scope of this study. However, some current nutrient studies are being conducted by personnel from Chico State University. These studies are still inconclusive, but have demonstrated that the nutrients in water flowing through the Eagle Lake Tunnel contain about 10 times the concentration of nutrients found in the main body of the lake. The probable reason for this is the algae concentration effect at the bay and channel leading to the tunnel. It is, therefore, apparent that water flowing from the tunnel could be an important nutrient removal mechanism for the lake system. Whether or not the effect is significant has not yet been determined.

Effects on Fish and Wildlife

The fish and wildlife at Eagle Lake are probably the lake's richest endowment by nature. They must therefore be given prime consideration in evaluating any proposed operation plan for the lake.

Since its beginning, Eagle Lake has fluctuated in response to nature's changes in the balance between outflow, evaporation, and inflow. Such fluctuations have made significant changes in the vegetative pattern and the habitat of the many species of fish and wildlife that use the lake. These changes have been detrimental to some forms of wildlife and beneficial to others. Biologically lake fluctuations are a vital part of the environment of Eagle Lake.

Comparison of past populations of fish and wildlife and lake levels indicate two critical elevations for maintenance of important habitat under the present lake regimen. For preservation of water-associated wildlife, such as the western and eared grebes, the water surface should be kept above elevation 5,100. Below this elevation the habitat in the littoral zone around the lake shoreline begins to deteriorate rapidly. The bottom of Eagle Lake is primarily sand, mud, and organic muck. Materials of this type that have been submerged for long periods of time are alkaline and infertile. When the lake drops in elevation and these soils constitute the littoral zone, very little shoreline and aquatic vegetation is produced. In Eagle Lake the most drastic changes in productivity take place in the north end where vast acreages of unproductive soils are exposed as the water level falls. All water-associated wildlife is affected, but low elevations are most detrimental to those birds such as grebes which nest in this area.

Eagle Lake becomes much more productive for fish if the level remains above elevation 5,106. Below this elevation the north end of the lake becomes too warm for trout during the summer, resulting in a major impact on the potential overall trout population since their living area is drastically reduced. Further reduction in fish habitat occurs as the lake drops below 5,100 and the aquatic vegetation of the lake is reduced. The tui chub are most affected by this since they depend on this growth for successful spawning and distribution throughout the lake. Since tui chub are an ecologically important species of fish in the lake, a significant reduction could have an adverse effect on the lake's ecosystem.

Discussed below is the impact each of the proposed alternatives evaluated in this study would have on the fish and wildlife of Eagle Lake.

Alternative No. 1 (Seal the Tunnel Completely)

Alternative No. 1 would provide the highest possible elevations of the lake surface. Assuming there would be no water quality problems associated with sealing the tunnel, this alternative would have the most beneficial effect on the fish and wildlife of the lake. The minimum elevation would be about 5,099 feet. Over the 96-year study period the lake surface would fall below 5,100 for 2 years and below 5,106 for 33 years. These elevations would have a minor effect on wildlife but a reduction in fish life would occur during an extended dry period. Although higher elevations are insured under this alternative, a larger difference exists between maximum and minimum elevations, thus creating a larger shoreline area subject to inundation.

Alternative No. 2 (Leave Tunnel As Is)

Alternative No. 2 would result in elevations below 5,106 for about 56 years out of 96 years, and below 5,100 for about 32 years. These periods of low water would cause considerable loss of fish habitat. Wildlife would also suffer from loss of food supply and nesting area.

Alternative No. 3 (Control Maximum Lake Level to 5,106 Feet)

Alternative No. 3 would result in a minimum elevation of 5,090 and levels below 5,100 for 33 years. The elevation would never exceed 5,106 except for short periods during the spring and summer and following years with extreme runoff. These elevations would be extremely detrimental to fish and wildlife.

Alternative No. 4 (Control Maximum Lake Level to 5,115 Feet)

Alternative No. 4 would cause elevations below 5,106 for 44 years and below 5,100 for 24 years during the 96-year study period. Minimum elevation reached would be 5,094. Wildlife and fish would suffer during the dry periods.

One other aspect which should be considered is the impact of the various alternatives on the Willow Creek trout habitat. Of the four alternatives, No. 2 (Leave Tunnel As Is) is the only one which insures continuation of existing conditions. The impact of the other alternatives is difficult to assess.

From the above discussion, it is apparent that sealing the tunnel (Alternative No. 1) would provide the best overall conditions for fish and wildlife. Controlling the lake at elevation 5,106 (Alternative No. 3) would cause the greatest damage. It is difficult to assess the relative impact of Nos. 2 and 4. Although No. 4 would hold higher average elevations, No. 2 would insure continued flows in Willow Creek.

Effects on Recreation

A major recreation activity on Eagle Lake is trout fishing. Therefore, the effect on trout is an important consideration in evaluating the impact each alternative has on recreation. Other considerations are the effect on camping, boating, waterskiing, swimming, hiking, hunting, and the general environment enjoyed by the recreationists.

The general impact each alternative would have on fish and wildlife was previously discussed. Alternative No. 1 (Seal the Tunnel Completely) would give the best insurance of protected fish and wildlife habitat. It therefore would provide the best fishing conditions for recreationists. However, as the lake rises much above its present level, some of the beaches and favorite shore fishing areas would be inundated.

The value of camping activity depends for the most part on other attractions such as fishing, swimming, boating, and the proximity of the campgrounds to the water's edge. Attractive campsites near the lake are therefore the most desirable. The present lake elevation of 5,107 is very favorable esthetically for campgrounds at the south shore of the lake. Elevations above this would inundate portions of Merrill Campground. However, excellent campground areas could be located above the historic maximum lake level of 5,125. As the lake recedes below the present elevation the distance from good campground sites to the lake is increased. Alternative No. 1, having the greatest overall fluctuation, would require the campgrounds to be located farthest from the water, which is objectionable to many recreationists. It would also require marinas, boat launching areas, etc., to be relocated more often as lake levels fluctuate. Therefore, this alternative and Nos. 2 and 4 would cause periodic inundation of good camp areas and render what is now a good camping area undesirable when the lake recedes. About $430,000 worth of present campsite development at Merrill Campground would be inundated under Alternative No. 1. Alternative No. 3 would inundate about $230,000 worth of development at the same campground. No estimates were made for the other alternatives. Since the U. S. Forest Service plans on moving campsites at Merrill Campground to a higher elevation, the loss of developed sites is not as important as the nearness of the lakeshore to the existing and planned sites.

Boating and waterskiing on Eagle Lake are probably affected the least by fluctuating lake elevations. In general, however, the higher the lake the more water surface and the better the boating. The most significant effect on boating would occur if the lake dropped below elevation 5,098 because then the north end would become too shallow for safe boat operation. Alternative No. 1, therefore, provides the best assurance for good boating.

Attractive swimming at the lake depends on the beach areas available. It is difficult to say what lake level would provide the best swimming. At the present elevation there are some good beaches. However, Gallatin Beach, which is an excellent swimming area, is now partially inundated. As the lake rises in elevation, other good beaches will also be inundated. However, beaches will migrate with the water level and will always be present to some extent. Elevations between 5,100 and 5,110 appear to be the most desirable for swimming beach development. Elevations below 5,095 expose large mudflats and are too far from forested areas. Alternatives Nos. 1, 2, and 4 appear to provide the greatest potential for swimming.

Hiking and big game hunting activities near Eagle Lake have little dependency on lake elevations. Therefore, the impact of various lake elevations on the value of these activities would be minor. Waterfowl hunting, however, is affected by lake elevations. It is difficult to say to what extent, except that at extremely low elevations the littoral zone around the lake would not provide good duck habitat and therefore would reduce the duck hunting area. Extremely high lake levels would also decrease the lake habitat for waterfowl due to the steepness of the shoreline.

The general environment and esthetic value of the lake is affected by lake elevations and by the amount of fluctuation. Generally, it can be said that the less the lake fluctuates the more esthetic value it possesses. This is especially true at Eagle Lake as fluctuation occurs over long periods of time, thus drowning out pine trees that have been established since the last high lake level. One exception is that dead trees left as the lake recedes provide perches for birds which increases the value of the area for bird watchers. Alternative No. 1 provides the highest lake surface; however, it also produces the greatest amount of overall fluctuation.

Effects on Shoreline Development

The effect of the various alternatives on camp and picnic grounds was previously discussed. Summer cabins and homes in the subdivisions at Eagle Lake are generally located above elevation 5,115. However, the lake would endanger four cabins in the Stones and Bengard Subdivisions if it should rise to an elevation of 5,115. In addition, several mobile homes would have to be moved. At elevation 5,120, two additional homes at Stones and Bengard Subdivisions would be threatened. Elevation 5,125 would endanger five more cabins at Stones and Bengard Subdivisions and one cabin at Spalding Tract. The remainder of the homes and cabins at the Spalding and Eagle Nest Tracts are above the maximum recorded elevation of 5,125.

Although several homes would be endangered or inundated by the higher elevations of Alternatives Nos. 1, 2, and 4, there would be considerable enhancement to these tracts from the higher lake elevations. No comparison was made of the benefits of the higher lake versus the detriments of some property loss.

The major development which is in danger of being inundated is State Route 139 along the north shore of the lake. Alternatives Nos. 1, 2, and 4 would eventually result in the inundation of approximately 5 miles of this highway. However, it would probably be longer before inundation would occur under Alternative No. 2. Relocation of this segment of the highway to the top of the bluff along the northeast side of the lake would solve the problem but would be costly. Alternative No. 3 would prevent inundation of the highway but due to its extreme fish and wildlife detriments, it does not appear to provide a practical alternative to relocating the highway.

The store at Eagle Lake Marina is located at approximately elevation 5,113. Like the highway, Alternatives Nos. 1, 2, and 4 would allow eventual inundation and require that the facility be moved to a higher location. Boat launching areas around the lake also would be affected by rising elevations; however, if they are located properly, the ramps can be extended with relative ease as the lake fluctuates.

The Spalding Tract Airport, located at an elevation of approximately 5,115 feet, would be subject to inundation under Alternatives Nos. 1 and 2. Inundation of this facility would be a detriment to those who use it; however, it could be beneficial to the nesting grebes in the vicinity which are adversely affected by airplanes.

The Chico State Biological Station is located at a sufficient elevation to not be endangered by any lake fluctuations considered herein.

Design and Cost

Cursory estimates were made of the total costs involved with implementation of each of the four alternatives. Estimates were made for the costs necessary for tunnel modification and the cost of relocation of campgrounds and other public development. About $700,000 of current recreation development improvements would be inundated if the lake rises to elevation 5,125. This would be reduced to about $500,000 if the maximum water surface were limited to elevation 5,115. No estimate was made of the value of private lands that would be damaged at these elevations, nor were estimates made for necessary channelization work in the Willow Creek Valley should substantial amounts of water be diverted through the tunnel. The cost of relocation of State Route 139 could approach $5,000,000 depending on the location of the selected route.

No attempt was made to compare costs and benefits of the four alternatives since no acceptable method is available for placing a dollar value on such things as the Eagle Lake trout, osprey, western and eared grebes, and the beauty and general condition of the environment of Eagle Lake.

Tunnel Description

The Eagle Lake Tunnel is 7,300 feet long, with 4,500 feet of its length lined with concrete. Typical sections and profiles are shown on Plate 2. A portion of the approach channel to the tunnel has been filled in with random material in an effort to stop lake water from flowing into the tunnel; however, water is seeping through the rubble beneath the imported material.

The face of the intake portal was covered with chain link fabric to close the tunnel to public access, but the closure has not been successful. The portal face is constructed of concrete, but the entire right half has fallen away, leaving an unstable pile of rock perched above.

The upper tunnel is concrete-lined for a distance of 250 feet downstream from the portal face. The remaining portion of the upper tunnel has some timber supports; however, some appear to be a hazard rather than a security measure. A sketch of this portion of the tunnel is shown on Plate 2. A headworks with two gates is mounted in the tunnel, but it is not functional and appears to be a hazard in its present location.

Historically, as the lake level dropped, this portion of the tunnel was excavated to its present invert in an attempt to keep the diversion operable. No apparent attempt was made to extend the concrete lining down to the existing invert or extend supports up to the base of the lining. The sole support of the lining is its upper bulb shape bearing against the surrounding fractured rock. The headgates appear to be supported by their headwall structure which is also undermined and without support from below.

A 60-inch-diameter corrugated metal pipe located 80 feet downstream from the gates conveys the flow to the tunnel below. An 8-foot-diameter unlined adit is located 3,600 feet upstream from the outlet portal. This was used for removal of material during construction. About 40 feet of the upper portion is now filled with material.

Only a cursory interpretation of the geologic profile of the tunnel was undertaken. The location of the contact zones for the various formations generally could not be located from within the tunnel because they were hidden by the tunnel lining. The location of the contact zone between the pyroclastic volcanics and the old lake deposits is critical in determining the cost and location of plugs because the amount of the grout curtain required must be known. Further geologic exploration should be accomplished before any construction in the tunnel is undertaken.

Project Design and Costs

Design and cost estimates were prepared for the two possible plug locations shown on Plate 2. The location near the construction adit is favored. This location appears to be the most feasible not only because of cost but also because of the structural competence of the surrounding rock at this site. The cost estimates and design considerations for necessary work within the tunnel at the construction adit plug location are described for each alternative.

Alternative No. 1 (Seal the Tunnel Completely). The estimated cost for sealing the tunnel is $30,000. Necessary work would be construction of a concrete plug in the unlined portion of the tunnel immediately upstream from the construction adit and closure of the tunnel entrance portal to public access. The basic criteria used for design is as follows:

1. To allow construction of the plug, a flow of 10 cfs would be diverted by a 4-foot-high sand bag cofferdam located immediately above the plug site with an 18-inch corregated metal pipe carrying water through the construction area.

2. For access, the construction adit would require clearing. After construction, the adit would be covered for public safety.

3. Maximum head against the plug would be 60 feet, which would exist when the lake was at elevation 5,125.

4. In addition to contact grout, a 25-foot grout curtain would be placed around the plug to prevent seepage.

5. Loose rock and debris would be removed from above the intake portal to reduce the existing hazard.

6. To prevent unauthorized access, the intake portal would be enclosed with a steel rack from the top of the portal down to elevation 5,120, using existing tunnel concrete lining and cross beams as a support frame.

7. Below elevation 5,120 the tunnel entrance would be enclosed and filled with riprap both inside and outside at a slope sufficient to eliminate future sloughing.

Alternative No. 2 (Leave Tunnel As Is). The only cost which would be incurred for this alternative would be for filling the existing channel from the sand dike to the intake portal to eliminate hazard and reduce seepage. Existing material available in the immediate vicinity of the tunnel intake portal would be used. It is expected that this could be accomplished for approximately $3,000.

Alternative No. 3 (Control Maximum Lake Level to 5,106 Feet). The estimated cost for this alternative is $40,000. The work necessary would be similar to Alternative No. 1 except that a 100-cfs control valve would be placed at the plug. The design criteria used in preparing these estimates are as follows:

1. Diversion and plug criteria for grouting are the same as for Alternative No. 1.

2. Adit clearing and closure are the same as for Alternative No. 1.

3. Maximum head against the plug would be 46 feet created by the lake at elevation 5,111.

4. A valve chamber would be located near the bottom of the access shaft.

5. A valve with a 100-cfs capacity would be placed in a 22-inch steel pipe passing through the plug.

6. The approach channel to the tunnel from the lake would be cleaned out to an invert elevation of 5,105 to allow water to enter the tunnel for diversion.

7. The intake portal would be enclosed with a steel rack from the top down to elevation 5,105 using existing tunnel concrete lining and beams. One additional beam would be necessary to completely frame the rack. This will provide a debris barrier and eliminate the safety hazard.

8. Debris would be removed, and timber supports, concrete lining, and headgate structures would be secured in the upper section of the tunnel to prevent damage and blockage at the tunnel.

9. Loose debris and rock would be removed above the intake portal for safety purposes.

Alternative No. 4 (Control Maximum Lake Level to 5,115 Feet). The estimated cost for this alternative is the same as for Alternative No. 3. The only difference in design criteria is that the maximum head against the plug will be 55 feet created by the lake at elevation 5,115.

Legal Considerations

A number of legal considerations would be involved in implementation of any of the alternatives discussed in this report. The following is a listing of the more important ones.

1. There are currently no existing appropriative water rights for the use of Eagle Lake water. The Tule Irrigation District at one time had appropriative rights to divert from the lake under State Water Rights Board Permits Nos. 782 and 783. These were revoked in 1959 because of nonbeneficial use in accordance with the stipulation of the permit.

2. An attempt was made to obtain a permit to divert Eagle Lake water in 1962 by several landowners from the Honey Lake Valley area. This was denied by the State Water Rights Board (predecessor to the State Water Resources Control Board) on the grounds that all Eagle Lake water was required in the lake for recreational, stockwater, and other related uses.

3. Maintenance of the level of Eagle Lake is a proper riparian use of Eagle Lake water, therefore it is not necessary for an agency to obtain water rights to seal the Eagle Lake Tunnel. However, the Honey Lake Land Company (Mr. Buell)

may have rights to new water generated inside the tunnel on private land, if this water would not have entered Willow Creek by natural processes or in the absence of the tunnel.

4. Water users from Willow Creek cannot claim a riparian or prescriptive right to water now leaking through the Eagle Lake Tunnel. However, the water which presently flows through the tunnel is supplied to these users in accordance with the Willow Creek decree.

5. Any agency who may wish to control the elevation of Eagle Lake by making releases through the Eagle Lake Tunnel must obtain an appropriative permit to divert the water. To obtain such a right it must be shown that the water would be put to beneficial use. Protection of recreational facilities around Eagle Lake may be such a use; however, it is doubtful that protection of State Route 139 would be considered a valid beneficial use.

6. Any agency desiring to divert water through the Eagle Lake Tunnel and Eagle Lake Canal would probably be required to compensate the Honey Lake Land Company for use of its facilities on its property. Sealing this tunnel could probably be accomplished without compensation to the company.

7. Any agency that diverts water through the Eagle Lake Tunnel would have to obtain flowage rights to divert water through the old Eagle Lake Canal in Willow Creek Valley if the amount of water diverted was substantial.

8. Riparian owners on Eagle Lake have a right to lake water for various uses including recreation. If the lake were to be operated at a lower level whereby the value of existing recreation facilities was substantially diminished, owners may have a claim for damages. Public domain lands which have not been withdrawn have no compensable riparian rights. On the other hand, withdrawn lands, such as those of the U. S. Forest Service, may have a compensable interest under the "reserved rights doctrine". However, the courts have not provided guidelines for the resolution of such basic issues as the quantity of water reserved or the use to which it may be put.

9. It is problematical whether sealing of the tunnel, which would result in the facilities of some littoral owners being flooded by the lake, could result in valid claims for damages.

10. If a maximum level is to be established, an agreement should be negotiated with all interested parties beforehand to avoid future litigation.

11. The Division of State Lands has jurisdiction over lands lying beneath the lake surface. The boundary of the

lake surface binding the jurisdiction of the State has not been established. However, a boundary has been established for the County's purposes of assessments and collection of taxes.

12. If Eagle Lake waters were to be managed by operation of the tunnel, or if the tunnel were to be sealed, Lassen County or the Lassen-Modoc Flood Control District could most feasibly take the necessary action. Neither the Department of Water Resources nor the Department of Fish and Game have authority to undertake construction work of this type in the absence of specific legislation authorizing them to do so. The State Division of Highways could possibly control the lake to protect the highway if appropriative water rights could be obtained. The Bureau of Land Management may be able to seal the tunnel if work was done on their property and could easily be accomplished. The U. S. Forest Service may be able to plug the tunnel under contract.

From the above, it is apparent that the implementation of either Alternatives Nos. 3 or 4 would require considerable legal negotiations and proof of beneficial use of water. Alternative No. 1 may involve some claims for damages to inundated lands. Alternative No. 2 would involve few, if any, legal problems.

Other Considerations

Several other factors may be affected by management of Eagle Lake waters. Many are not identifiable at this time and would appear only after a plan is put into effect. Others would become evident after further study is made. These would be primarily in the area of water quality and the ecosystem in general.

One area which would be affected by any of the alternatives is the Willow Creek-Honey Lake area. Little work was done in evaluating the possible impacts in this area. There is currently about 9.5 cfs flowing from Eagle Lake into Willow Creek. During the summer this water is fully used for irrigation purposes. Sealing the tunnel would reduce or eliminate this flow.

Under Alternatives Nos. 3 and 4, whereby larger quantities of water would be diverted from the lake, considerable work would be necessary through Willow Creek Valley to restore the old Eagle Lake Canal. This could be costly and involve much litigation. Diversion of water from Eagle Lake would cause slight rises in the level of Honey Lake. However, they would probably not be significant.

CHAPTER VI. SUMMARY AND FINDINGS

Eagle Lake is the second largest natural freshwater lake in California and is well known for its unique fish and wildlife. Around its shore are located one of the last known nesting colonies of ospreys, and probably the largest nesting colonies of western grebes and eared grebes in the Western United States. It is also the home of the unique Eagle Lake trout which is native only to Eagle Lake.

Eagle Lake lies within a closed basin having no natural surface outlets; its elevation, therefore, fluctuates with the variations of inflow. Since 1950 the lake's water level has been rising. Today, this high elevation lake is one of the most beautiful natural bodies of water in California, with clean sandy beaches, tree covered slopes, diverse species of fish and wildlife, and clear water. As the lake surface has risen, uncontrolled leakage through the old Eagle Lake Tunnel has increased, thus allowing more water to leave the basin. Roads and lakeshore developments which were constructed when the lake level was low are now being threatened with inundation. The water quality of the lake also presents a potential problem as the eutrophication process appears to be accelerating.

This report presents the results of a study undertaken to evaluate the problems and to investigate the possibility of improving the lake environment by various operational plans. Four alternative operational plans for the control of the water surface elevation of Eagle Lake were evaluated: (1) seal tunnel completely, (2) leave tunnel as is, (3) control maximum lake level to 5,106 feet, and (4) control maximum lake level to 5,115 feet.

Table 4 presents a summary of the alternative operational plans and their effects.

Findings

1. Eagle Lake is the second largest freshwater lake in California and provides habitat for unique fish and wildlife species. The California Protected Waterways Plan has classified the lake as one of California's "extraordinary scenic, fishery, wildlife, and recreation waterways in 1970". Protection of the unique ecosystem should be the first and foremost consideration in any plans involving the lake.

2. The hydrologic and biologic aspects of the Eagle Lake Basin are extremely complex and additional study is required to better define their interrelationships. Hydrologic studies should include a more accurate definition of the quantity of ground water inflow and outflow from the lake. Biologic studies should include continued collection of data and evaluation of the nutrient balance. Fisheries studies should attempt to determine the tolerance of the Eagle Lake trout to salts and nutrients in the lake.

TABLE 4

SUMMARY OF EFFECTS OF OPERATIONAL ALTERNATIVES

Effects on:	Alternative No. 1 (Seal Tunnel Completely)	Alternative No. 2 (Leave Tunnel As Is)	Alternative No. 3 (Maximum Lake Elev. 5106)	Alternative No. 4 (Maximum Lake Elev. 5115)
Lake Levels Over Study Period	Maximum - 5125 feet Minimum - 5099 feet Average - 5110 feet Elevation below 5100 feet about 2% of the time	Maximum - 5116 feet Minimum - 5092 feet Average - 5104 feet Elevation below 5100 feet about 33% of time	Maximum - 5108 feet Minimum - 5090 feet Average - 5101 feet Elevation below 5100 feet about 34% of time	Maximum - 5117 feet Minimum - 5094 feet Average - 5106 feet Elevation below 5100 feet about 25% of time
Water Quality	Max. Salt Concentration-600 ppm Min. Salt Concentration-300 ppm No nutrients removed	Max. Salt Concentration-750 ppm Min. Salt Concentration-300 ppm Some nutrients removed	Max. Salt Concentration-700 ppm Min. Salt Concentration-250 ppm Some nutrients removed	Max. Salt Concentration-750 ppm Min. Salt Concentration-300 ppm Some nutrients removed
Fish	Insures adequate water and habitat for all species. May reduce Willow Creek fishery.	Reduced habitat during drought. Maintains current Willow Creek fishery.	Reduced habitat during drought. Considerable reduction in numbers. May reduce Willow Creek fishery.	Reduced habitat during drought. May reduce Willow Creek fishery.
Wildlife	Insures adequate habitat and food supply.	Reduced nesting areas around shoreline. Some reduction in food supply during drought.	Reduced nesting areas around shoreline. Some reduction in food supply during drought.	Reduced nesting areas around shoreline. Some reduction in food supply during drought.
Recreation	Maximum fluctuation requires campsites farthest from lake. Good esthetics and boating. Available beaches inundated most of the time. Insures against mudflats along shore.	No inundation of lands and development above 5116 feet elevation. Value of all recreation activities reduced following drought.	Lands and development above 5111 feet elevation protected from inundation. Minimum fluctuation. Value of all recreation activities reduced following drought.	Lands and development above about 5118 feet elevation protected from inundation. Value of all recreation activities reduced following drought.
Shoreline Development	Maximum damage. Inundation of State Route 139, E. L. Marina, and some of Merrill Campground.	Inundation of State Route 139, E. L. Marina, and some of Merrill Campground.	Minimum damage. No existing development affected.	Inundation of State Route 139, E. L. Marina and some of Merrill Campground.
Estimated Construction Cost (excluding work in Willow Creek Valley)	$30,000	$3,000	$40,000	$40,000
Legal Ramifications	Possible litigation for reducing flow in Willow Creek and for inundation of littoral lands around the lake.	No significant legal problems.	Considerable water right and land easement legal proceedings necessary.	Considerable water right and land easement legal proceedings necessary.
Willow Creek Valley	Eliminates flow of water into Willow Creek Valley for irrigation.	Continues irrigation water supply to Willow Creek Valley.	Provides intermittent irrigation supply. Considerable work and cost necessary to repair E. L. Canal.	Provides intermittent irrigation supply. Considerable work and cost necessary to repair E. L. Canal.

3. It appears that eutrophication of Eagle Lake has accelerated in recent years. However, little is known about the nutrient load in the lake or the lake's capacity to assimilate additional nutrients.

4. The water level of Eagle Lake has fluctuated appreciably over the years, generally in response to variations in inflow. This general pattern will continue under any of the alternative plans evaluated, although the range and amount of fluctuation would be reduced with some of them.

5. The most favorable lake elevations from the standpoint of recreation and fish and wildlife habitat are above 5,100 feet. The September 1972 elevation of the lake was 5,106 feet. Levels above 5,106 feet would inundate campgrounds, beaches, and other shoreline developments, and would kill pine trees which have established themselves along the shore. Lake elevations much below 5,100 feet would result in serious fish and wildlife problems.

6. Any plan to modify the existing condition of Eagle Lake through alteration of the Eagle Lake Tunnel would involve legal problems.

7. Sealing the tunnel completely (Alternative No. 1) would keep the lake level above 5,100 feet the greatest amount of the time. Thus, it appears to be the most advantageous for fish and wildlife. However, it causes the greatest amount of inundation of campgrounds, beaches, and shoreline developments. It would eliminate one possible means of slowing eutrophication of the lake since nutrient-rich water could not be exported through the tunnel once it was sealed, if such export were found to be the best alternative to control eutrophication. It may be harmful to the fishery in Willow Creek, would eliminate an irrigation water supply to users in Willow Creek, and may involve litigation from landowners around the lake and along Willow Creek.

8. Allowing the Eagle Lake Tunnel to continue to leak (Alternative No. 2) would provide a reasonable interim solution to the lake's problems, at least until current water quality studies by the State Water Resources Control Board and Chico State University are completed. This plan would result in less lake fluctuation than sealing the tunnel completely, remove some nutrients from the basin, continue to provide supplemental irrigation water to the Willow Creek area, maintain the fishery in Willow Creek, involve only minor legal problems, and be inexpensive to implement. However, if the tunnel were allowed to leak indefinitely, the lake elevation would remain below 5,100 feet about 33 years out of 100, which would be detrimental to fish and wildlife. It would also cause inundation of some shoreline developments.

9. Controlling the lake's maximum elevation to 5,106 feet (Alternative No. 3) would protect State Route 139 and essentially all other shoreline developments from inundation, reduce lake fluctuation to a minimum, remove nutrients from the basin, and provide some supplemental irrigation water to the Willow Creek area. However, it would be costly to implement, cause extremely low lake levels, cause extensive loss of fish and wildlife, and create an esthetically unattractive body of water. It is, therefore, not considered an acceptable alternative.

10. Controlling the lake's maximum elevation to 5,115 feet (Alternative No. 4) would fix the maximum level of inundation, protect some of the existing shoreline developments, remove some nutrients from the basin, and reduce the amount of lake fluctuation. This plan could be accomplished with very infrequent releases through the Eagle Lake Tunnel. However, this alternative would allow the lake level to go below the 5,100-foot elevation about 25 years out of 100, cause inundation of some existing shoreline developments, reduce flows in Willow Creek, and be costly to implement.

11. It appears that the best long-term solution to the problems of Eagle Lake would be to seal the tunnel by construction of a plug and control valve. This would keep the lake level above 5,100 feet as often as possible and yet provide operational flexibility so that releases could be made if future study and conditions show that to be feasible. Pending completion of needed hydrologic and biologic studies, necessary geologic, engineering, and legal work should be undertaken to determine the best method of constructing a plug and control valve in Eagle Lake Tunnel.

12. Lassen County, in cooperation with the U. S. Bureau of Land Management and the U. S. Forest Service, should have a principal decision-making role in any activity involving control of Eagle Lake.

APPENDIX

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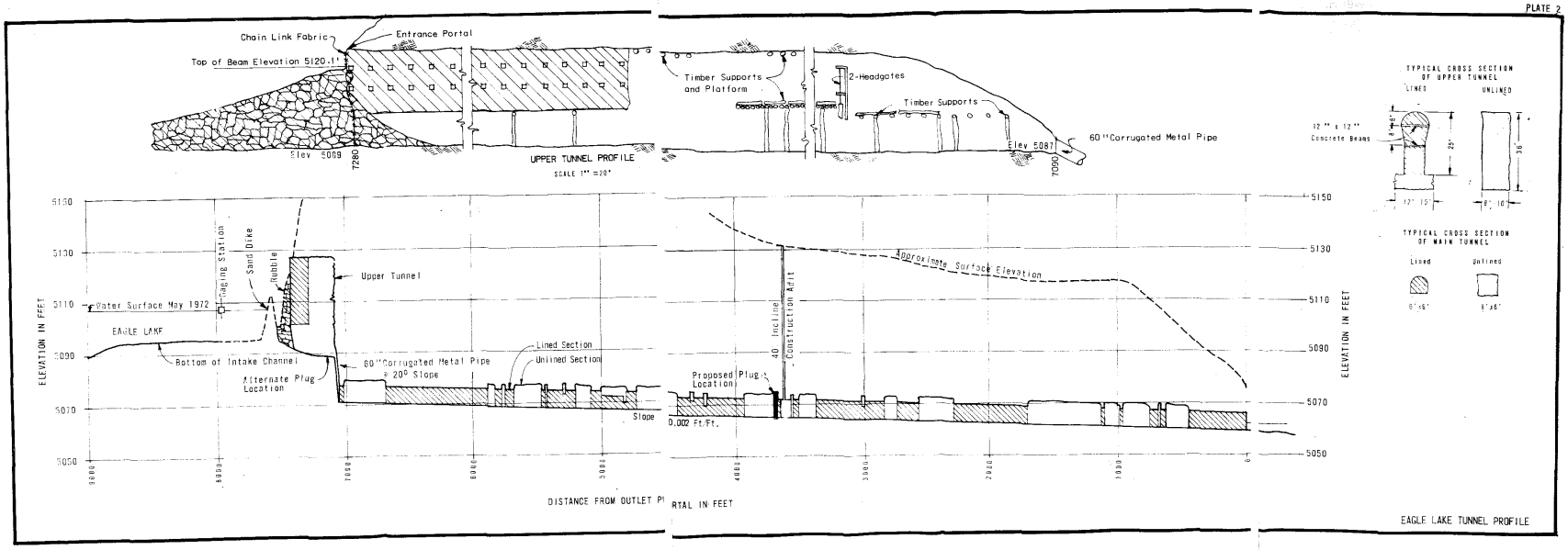
PLATE 2



EAGLE LAKE TUNNEL PROFILE

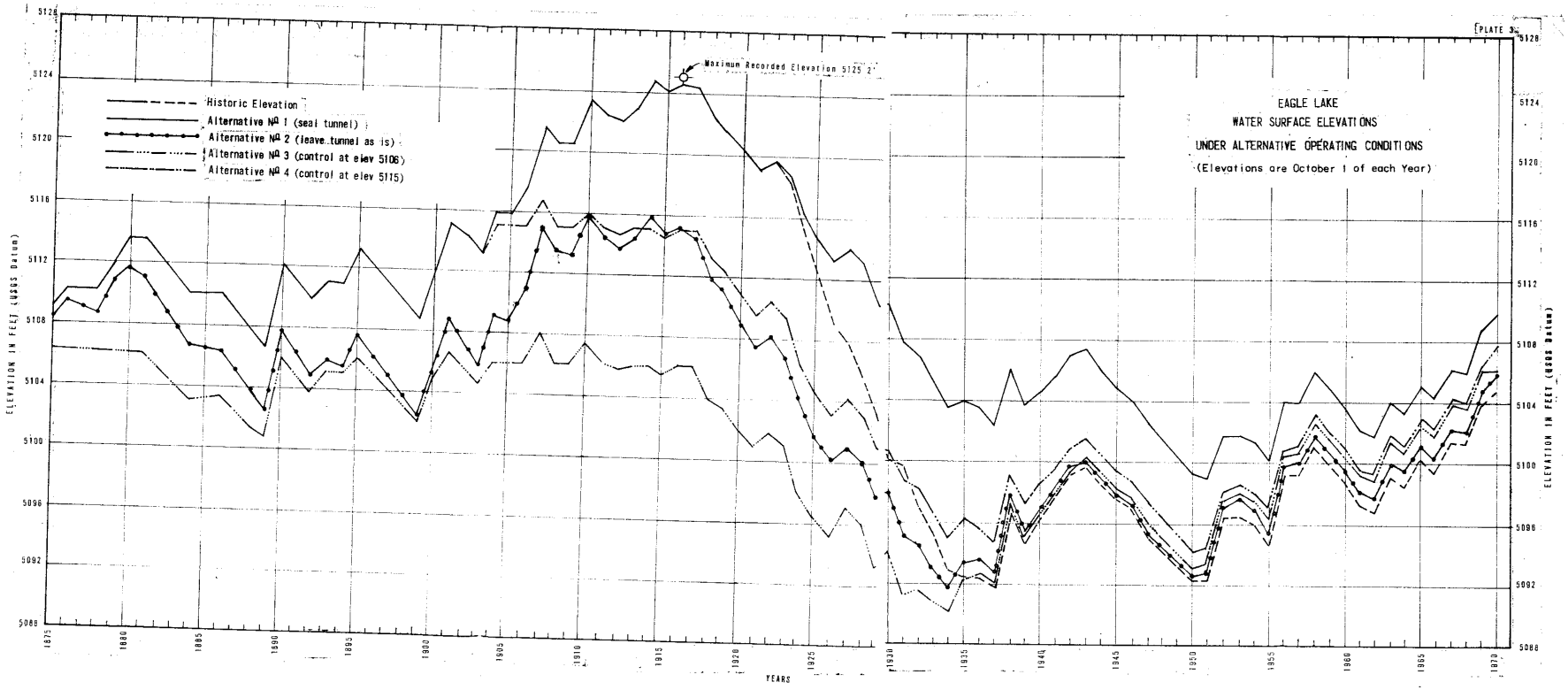


PLATE 3
EAGLE LAKE
WATER SURFACE ELEVATIONS
UNDER ALTERNATIVE OPERATING CONDITIONS
(Elevations are October 1 of each Year)
Historic Elevation
Alternative Nº 1 (seal tunnel)
Alternative Nº 2 (leave tunnel as is)
Alternative Nº 3 (control at elev 5106)
Alternative Nº 4 (control at elev 5115)
Maximum Recorded Elevation 5125.2'
ELEVATION IN FEET (USGS Datum)
YEARS
5128
5124
5120
5116
5112
5108
5104
5100
5096
5092
5088
1875
1880
1885
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